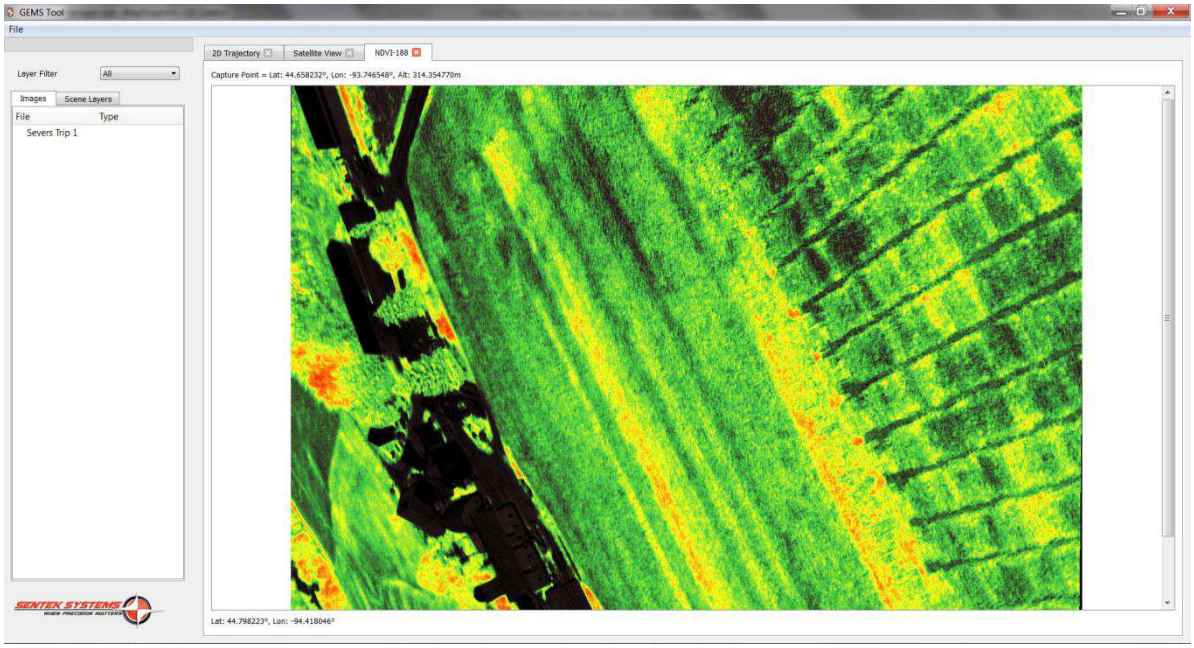
Geo-localization and Mosaicing System (GEMS Tool)

Software Integration Manual



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Preface

As a part of our commitment to customer support Sentek has developed this software user manual. It is a volume of technical documentation which supplements our GEMS product brochures and data sheet to aid the system integrator in proper use of the GEMS post-processing software.

Warranty

Sentek's warranty obligations for this hardware product are limited to the terms set forth herein: Sentek warrants this Sentek-branded hardware product against defects in materials and workmanship under normal use for a period of ONE (1) YEAR from the date of purchase by the original end-user purchaser ("Warranty Period"). If a hardware defect arises and a valid claim is received within the Warranty Period, at its option and to the extent permitted by law, Sentek will either (1) repair the hardware defect at no charge, using new or refurbished parts that are equivalent to new in performance and reliability, (2) exchange the product with a product that is new or refurbished that is equivalent to new in performance and reliability and is at least functionally equivalent to the original product. The warranty does not cover damage caused by accident, misuse or unauthorized repair, damage caused by impact, improper care or storage or leakage of batteries. The GEMS payload should be connected to an independent power source to maintain the payload is a non-mission critical system. Sentek Systems is not responsible and cannot be held liable for any damages if the payload is connected to the UAV main battery and made into a mission critical system. If modifications to the GEMS kit have been made (some examples, removing EMI shields on the payload, using a different jumpdrive than supplied in kit, removing or altering cameras, altering lenses or filters, using a different GPS antenna) the warranty is void and no longer valid and Sentek is not responsible for technically supporting these alterations.

Obtaining Warranty Service:
All shipping, insurance, duties and other incidental costs incurred to return the product to Sentek are at the expense of the owner of the product. Sentek will pay the cost of insured shipping only, FOB St. Louis Park MN USA when returning the product after completion of Warranty Service. All other expenses, duties, taxes and other incidental costs are at the expense of the owner. This warranty is in lieu of all other express or implied warranties and of any other obligation on the part of Sentek Systems LLC except for the obligations provided by applicable law.

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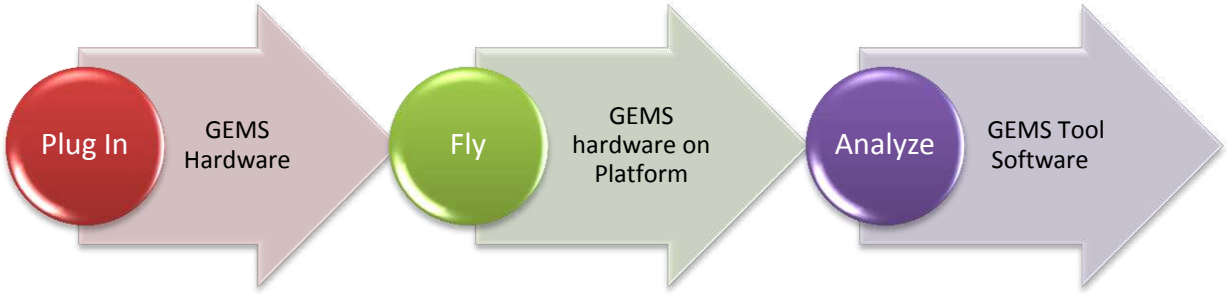
For immediate technical assistance please email techsupport@senteksystems.com this will automatically open a support ticket and be assigned to an application engineer. Additionally, our website (www.senteksystems.com) provides a contact us page that will email a representative who will contact an application engineer to assist with your technical needs.

1. Software Description

1.1. Overview

The GEMS Tool is a software graphical user interface (GUI) used to visualize the flight data gathered from the GEMS hardware payload. It is designed specifically for tight integration with the GEMS Precision Agriculture hardware platform and is available free of charge with the GEMS hardware kit purchase.
The software will automatically access the sub-images recorded to the storage media (jump drive) from the flight and the corresponding metadata. Orthomosaiced RGB, NIR, and NDVI imagery will be automatically generated. GPS coordinates of an RGB, NIR, or NDVI image pixel are available on both the individual images and the mosaiced images.

Figure 1 Workflow Process



- Power from UAV battery
- USB jump drive
- GPS supplied Antenna
- Remote LED board (supplied with kit but use is optional)

- Automatically acquires GPS
- Automatically detects take off & landing events which activate cameras
- Automatically stores images to jump drive

- Plug in jump drive to ground PC or laptop
- Mosaics imagery
- Geo-locates imagery
- RGB, NIR, & NDVI imagery analyzed with GPS pixel coordinates in one flight for all images acquired and for mosaiced imagery

2. Installation

Currently, the GEMS Tool is only compatible with Windows operating systems (Windows 7 and Windows 8). The provided GEMS 2.0 software installer is 64 bit.

- Double click the GEMS.msi file and the installer will prompt you through the defaults.

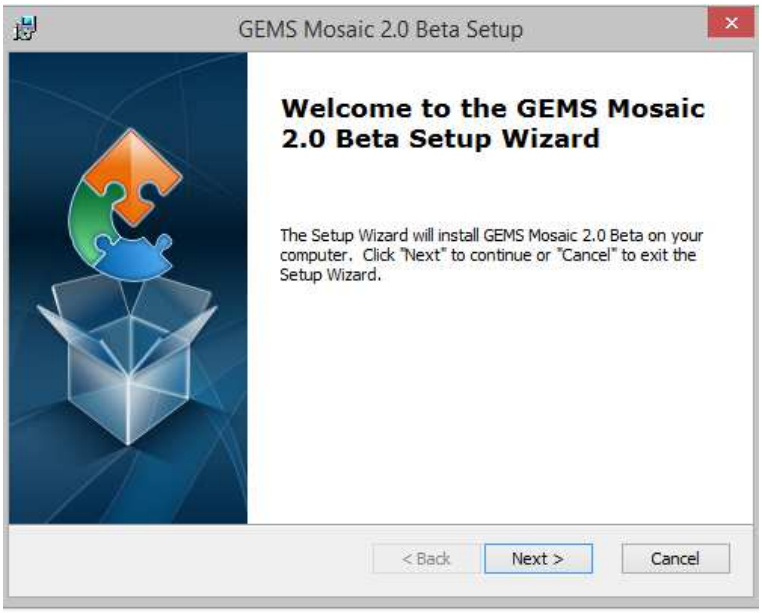

GEMS Mosaic 2.0 Beta Setup
Welcome to the GEMS Mosaic 2.0 Beta Setup Wizard
The Setup Wizard will install GEMS Mosaic 2.0 Beta on your computer. Click "Next" to continue or "Cancel" to exit the Setup Wizard.
< Back
Next >
Cancel

Figure 2 Select Next

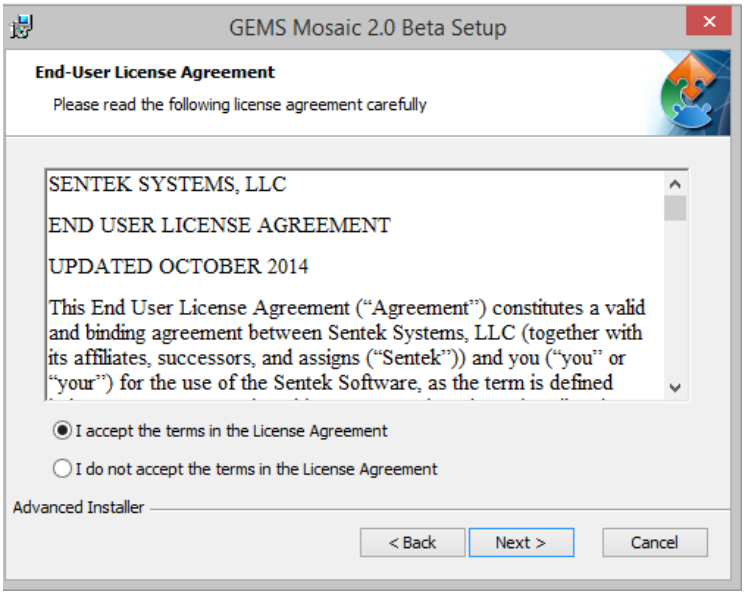

GEMS Mosaic 2.0 Beta Setup
End-User License Agreement
Please read the following license agreement carefully
SENTEK SYSTEMS, LLC
END USER LICENSE AGREEMENT
UPDATED OCTOBER 2014
This End User License Agreement ("Agreement") constitutes a valid and binding agreement between Sentek Systems, LLC (together with its affiliates, successors, and assigns ("Sentek")) and you ("you" or "your") for the use of the Sentek Software, as the term is defined
I accept the terms in the License Agreement
I do not accept the terms in the License Agreement
Advanced Installer
< Back
Next >
Cancel

Figure 3 Accept the terms of the Software User License and press Next

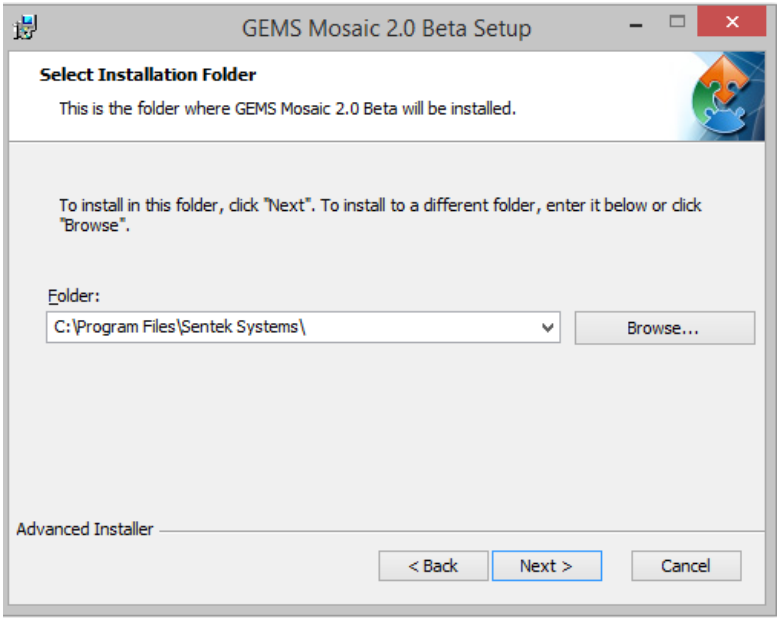

GEMS Mosaic 2.0 Beta Setup
Select Installation Folder
This is the folder where GEMS Mosaic 2.0 Beta will be installed.
To install in this folder, click "Next". To install to a different folder, enter it below or click "Browse".
Folder:
C:\Program Files\Sentek Systems\
Browse...
Advanced Installer
< Back
Next >
Cancel

Figure 4 By default the software will be placed in this directory if satisfactory select Next

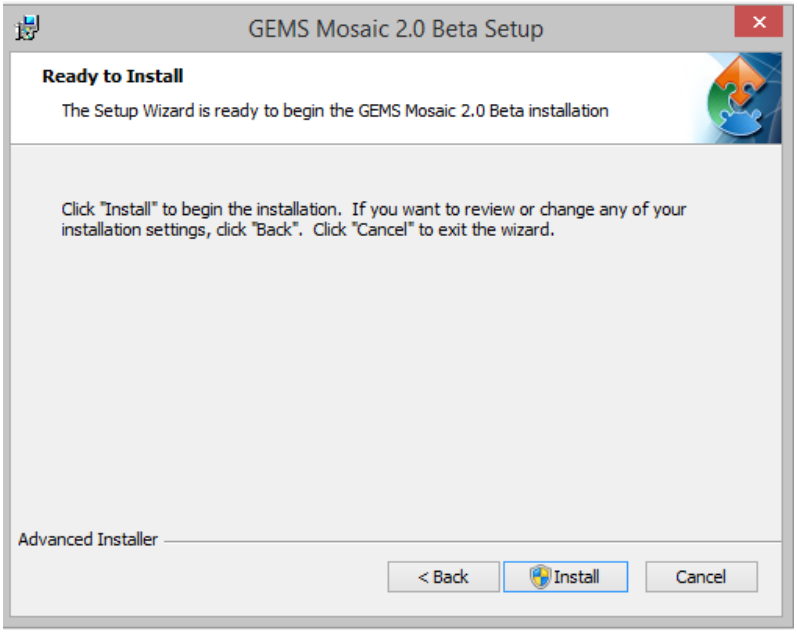

GEMS Mosaic 2.0 Beta Setup
Ready to Install
The Setup Wizard is ready to begin the GEMS Mosaic 2.0 Beta installation
Click "Install" to begin the installation. If you want to review or change any of your installation settings, click "Back". Click "Cancel" to exit the wizard.
Advanced Installer
< Back
Install
Cancel

Figure 5 Select Install. Most Windows machines will bring up another prompt asking if you want the software to allow to make changes to your computer select yes and press the Install button.

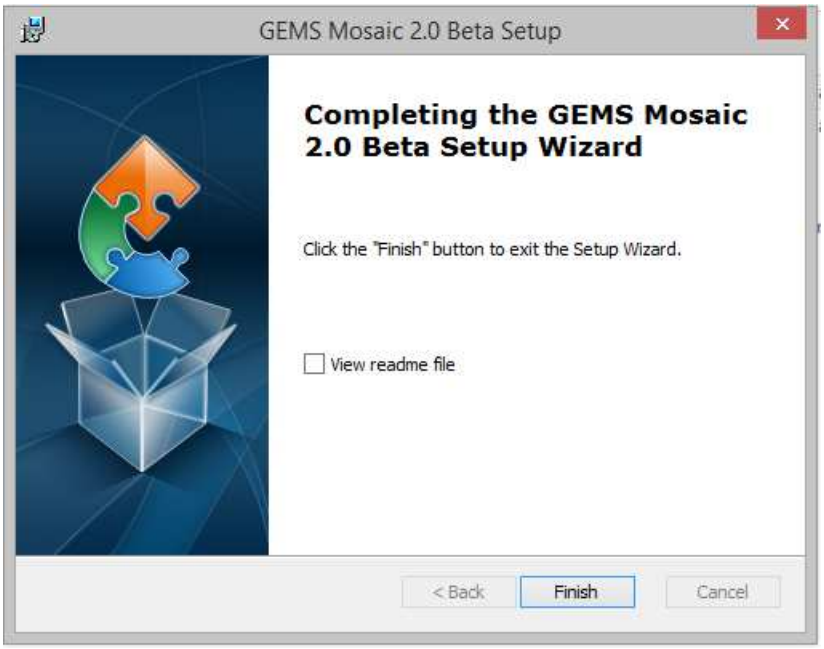

GEMS Mosaic 2.0 Beta Setup
Completing the GEMS Mosaic 2.0 Beta Setup Wizard
Click the "Finish" button to exit the Setup Wizard.
View readme file
< Back
Finish
Cancel

Figure 6 Last Screen Select Finish

3. Quick Start

After the payload has been powered down, the jump drive can safely be removed and plugged into a laptop or desktop. Every flight the GEMS hardware automatically labels a new folder with the following label structure Fight Data (Week=X TOW=H-M-S). Where X, H, M, and S are numbers specifying the instant that data collection began for the associated flight. X is the GPS week number of the starting instant. H, M, and S represent the hours, minutes, and seconds, respectively, into the GPS week of the starting instant. These values collectively define the GPS time of the instant that data collection began, and this can be converted to UTC or local time through various time conversion libraries.

For example, Flight Data (Week=1813 TOW 161-54-19)

Loading FlightData.bin File:

Double Click the GEMS Tool Icon on the desktop.

The user will be prompted to load a file. The GEMS Tool is designed to be used to analyze imagery and flight data. The first screen that will open will prompt you to load a FlightData.bin file. If you have already flown load your flight of interest navigate to the folder and select the corresponding flight data. If you have not flown yet with the GEMS sensor then press cancel.

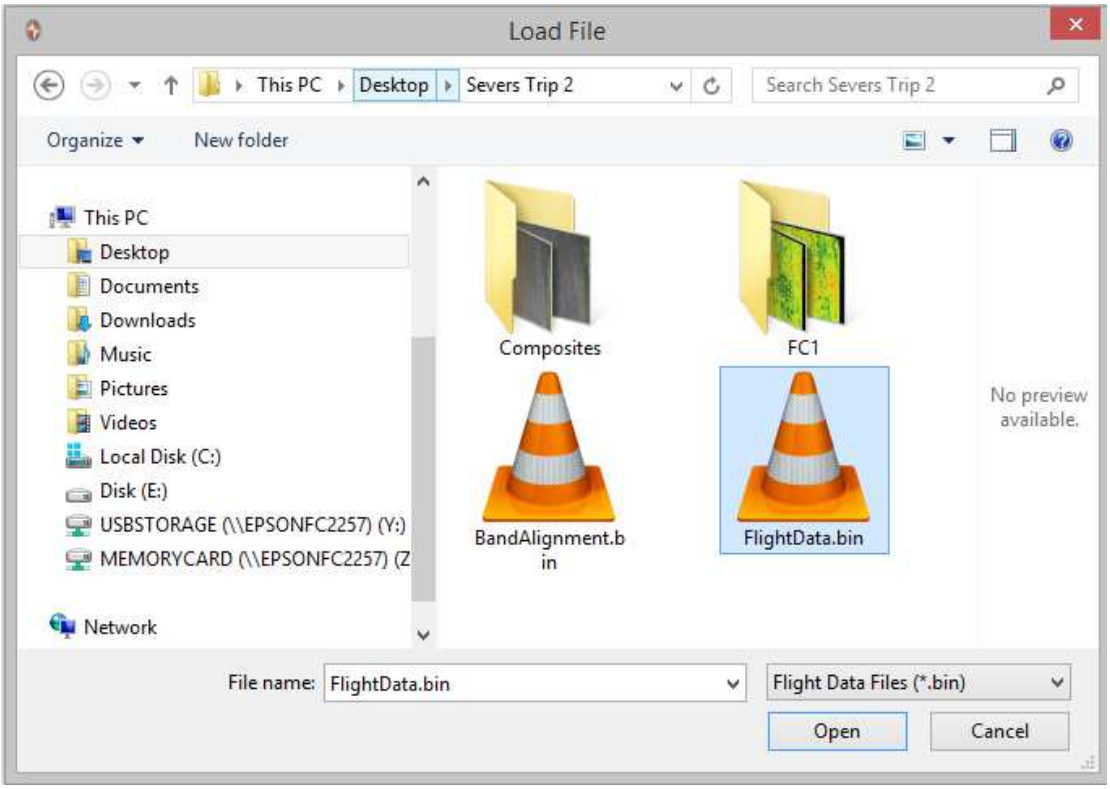


Figure 7 Prompt to load FlightData.bin file. If you have already flown navigate to your folder and load FlightData.bin If not select cancel.

- Navigate to the Flight Data folder that was saved by the GEMS hardware payload. The folder created by the hardware will contain all the raw images that were gathered in flight as well as the FlightData.bin file.
- Select the FlightData.bin file and press open.

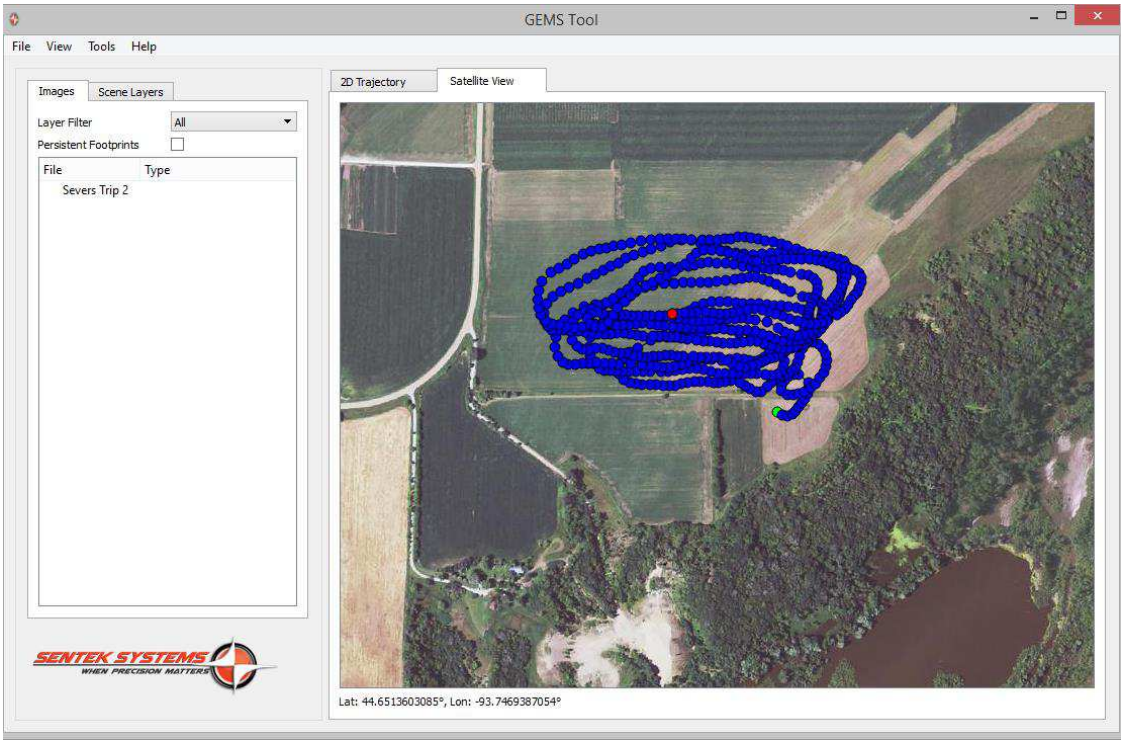


Figure 8 Once a flight has been loaded this is the home screen that you will see with your flight trajectory

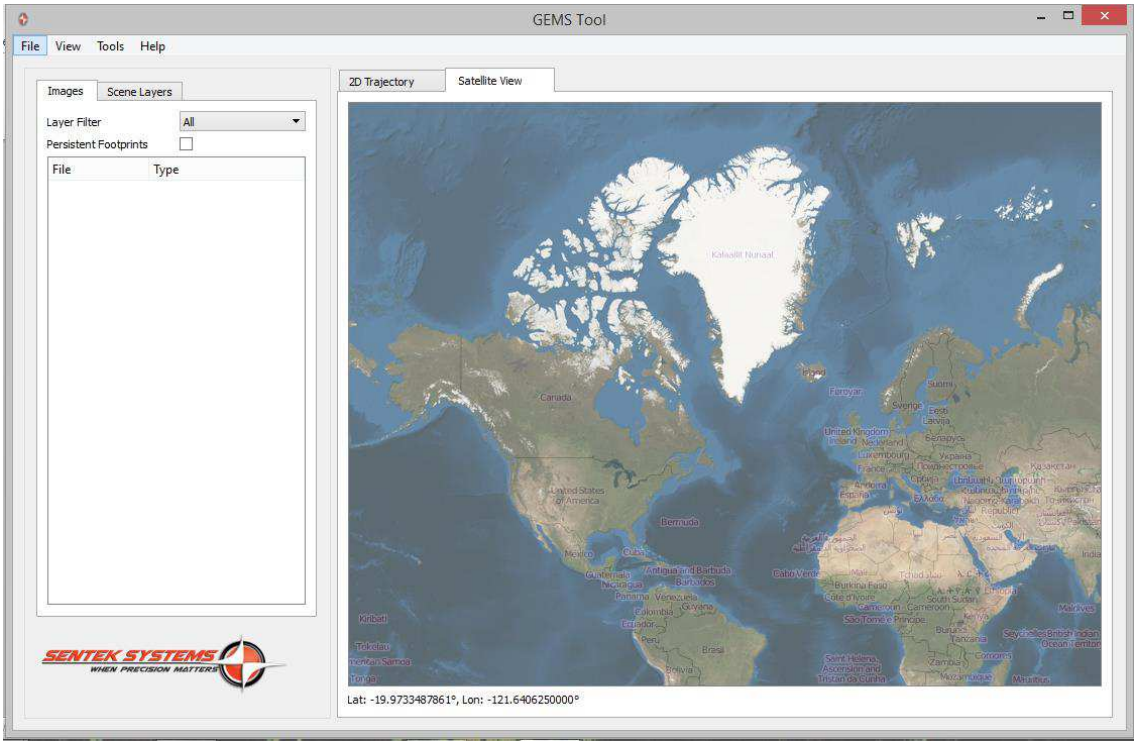


Figure 9 If you selected cancel for the load file prompt this is your home screen in the GEMS tool. You can always load a FlightData.bin file through the File menu and select Load.

- The GEMS Tool will automatically load all metadata for the corresponding flight and all sub-images.

- If an internet connection is present the 2D flight trajectory will be overlaid on satellite imagery of the location flown. If internet is not available the 2D trajectory will be the default tab.

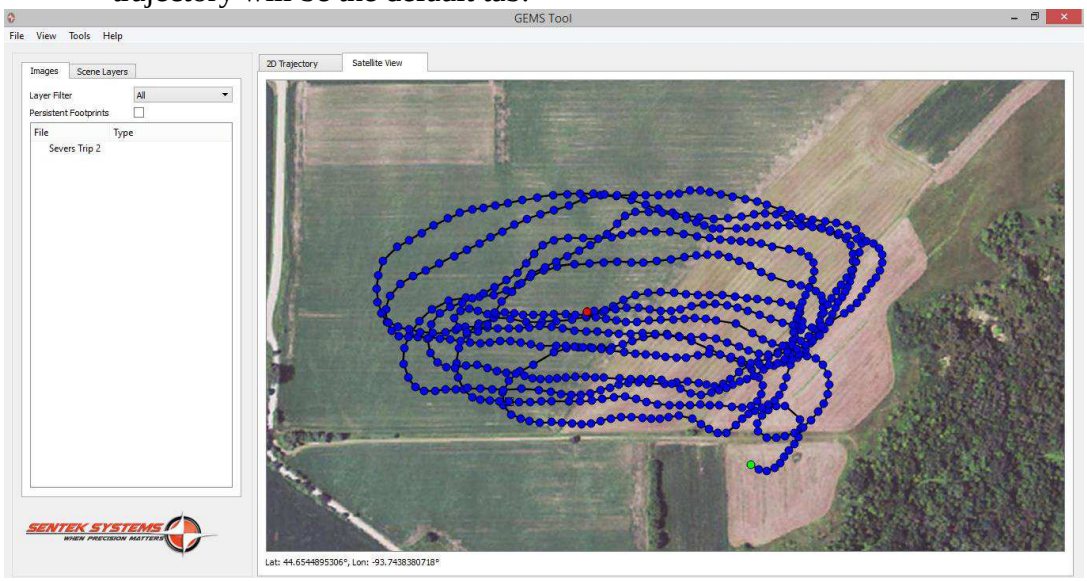


Figure 10 Default Tab with internet connection for visualizing 2D flight trajectory on satellite imagery

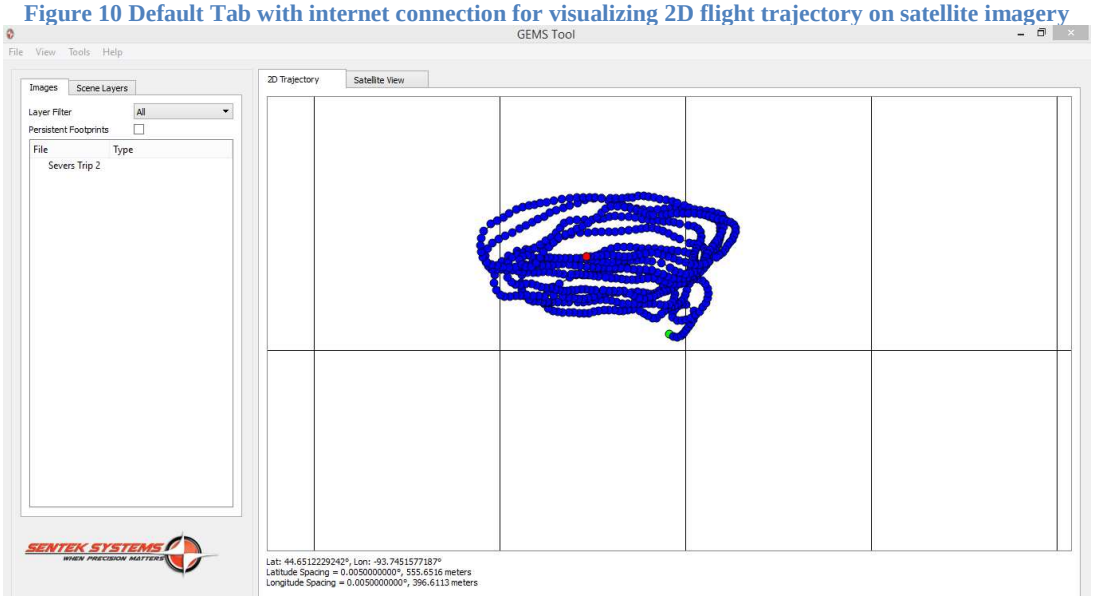


Figure 11 Default Tab without internet connection for visualizing 2D flight trajectory on grid

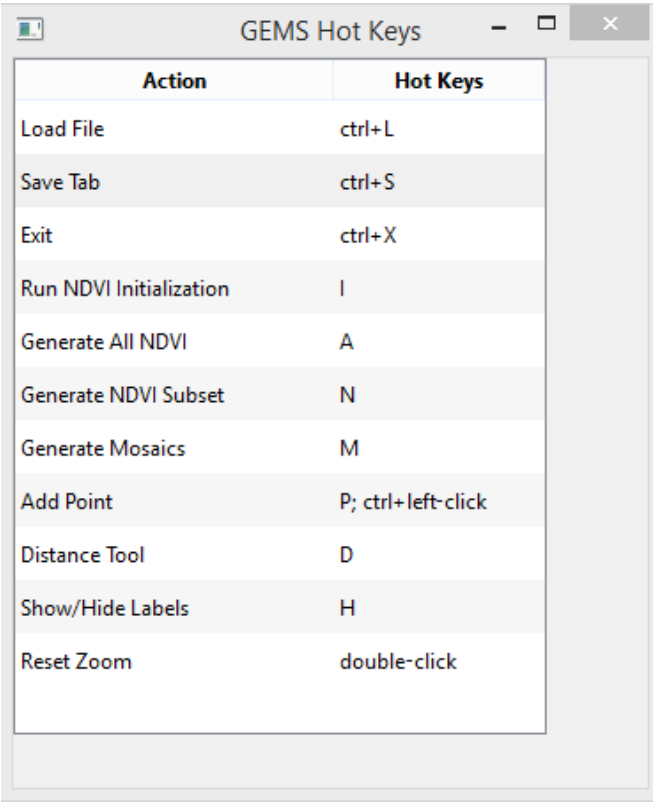
4. Basic Features & Navigation

Basic feature functionality includes:

- Pan, zoom, and scroll using the center mouse wheel for all satellite and 2D trajectory imagery views.
- Pan, zoom, and scroll on all sub-images and mosaic tiles. Hold ctrl and use center wheel on mouse for zoom. Zoom activates pan and scroll features.

- Geo-location of pixel coordinates displayed on bottom toolbar as mouse scrolls across imagery on satellite, 2D trajectory, and all sub-imagery and mosaic tiles.

4.1.Hotkeys



Action	Hot Keys
Load File	ctrl+L
Save Tab	ctrl+S
Exit	ctrl+X
Run NDVI Initialization	I
Generate All NDVI	A
Generate NDVI Subset	N
Generate Mosaics	M
Add Point	P; ctrl+left-click
Distance Tool	D
Show/Hide Labels	H
Reset Zoom	double-click

Figure 12 Basic Functionality in Hotkeys

4.2.Images Layer Tree

The left side of the GUI is used for navigation and illustrates the active layers and tiles that can be viewed in the tabs. There are two run modes for mosaicing Fast Mosaics and Fine Mosaics. This is further described in Section 4.5.5 below. Once the Run mode has generated data the navigation tree will populate with results under the subcategory. There is a layer filter that filters between tiles of different layers. For example, if the user has an older GPU more tiles per layer may be generated. Therefore to easily navigate only RGB layers the filter would select RGB and all the generated RGB tiles will be populated in the Fast mosaics and Fine mosaics sub-categories. The global units pulldown sets the label display units when using the distance measurement tool. For example, if meters are selected all distance measurement labels will be in meters but if changed to feet the label will update to feet. The persistent sub-image footprints show all image footprints overlaid on the satellite imagery. The persistent tile footprints shows the user how many mosaiced tiles were generated based on their computer's GPU or CPU

hardware capabilities and overlay them on satellite imagery with tile numbers. After tiles are generated based on hardware capabilities the software generates a Mosaic Overview that combines the tiles at a down sampled size to display the imagery as a single tile per layer (RGB, NIR, NDVI). On older hardware with less capable GPUs more tiles may be necessary and the graphical user interface will number the tile per box that corresponds to the navigation tile number displayed in the navigation tree. To view any mosaic tile or mosaic overview tile double click the tile in the navigation window and it will open in a new tab.

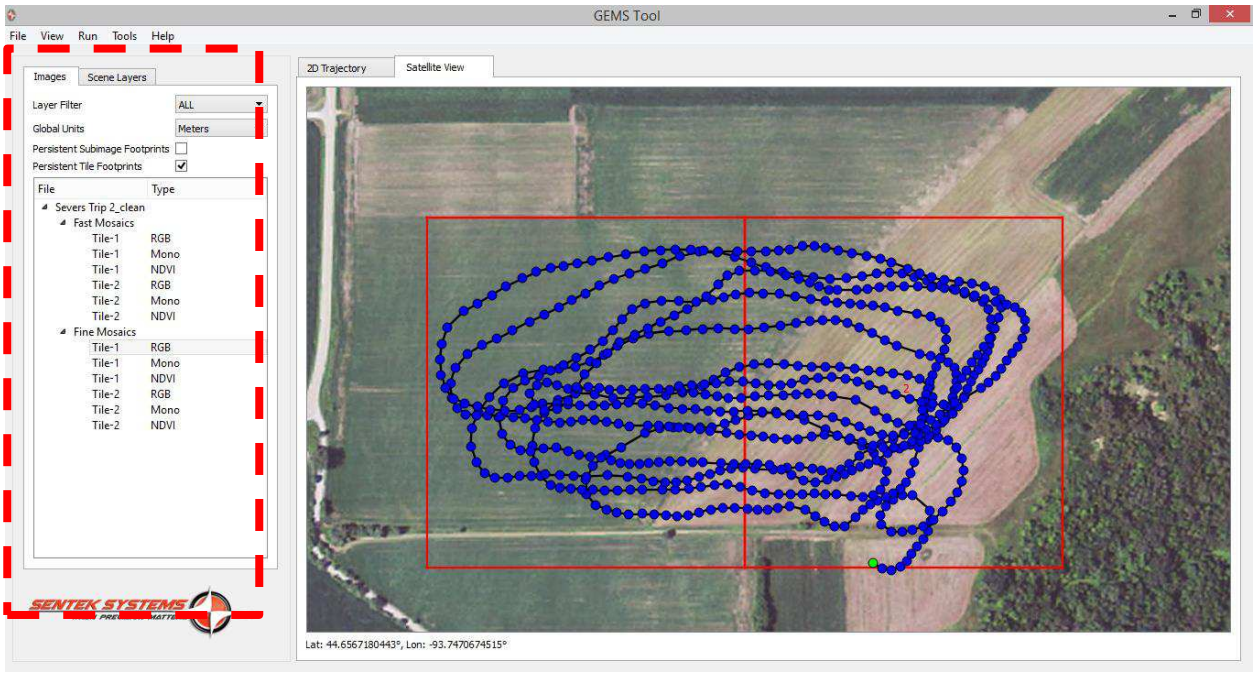


Figure 13 Image Layer Tree to use for navigation of Mosaic Tiles with mosaic tile footprints

4.3. Satellite Layer Tree

The user can adjust the settings on the satellite imagery layers. To do this select the tab labeled scene layers shown below. To toggle between the satellite imagery and the street view drag the slider from the right (default) to the left.

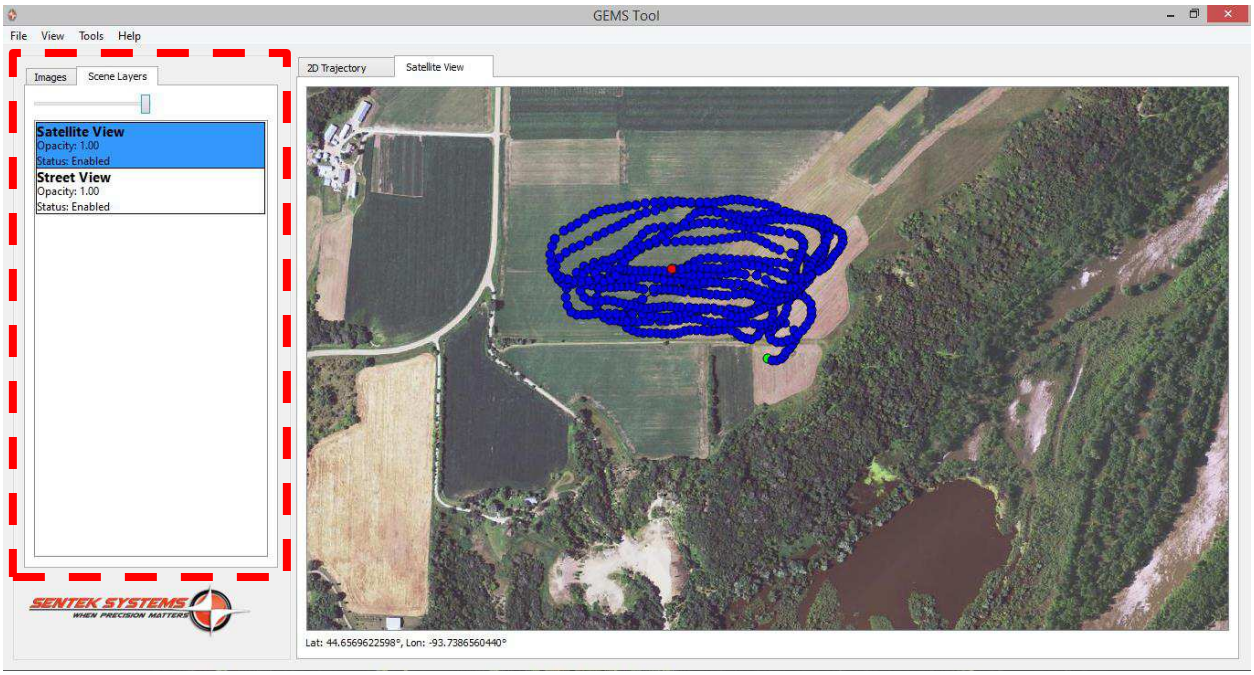


Figure 14 default settings Satellite Imagery.

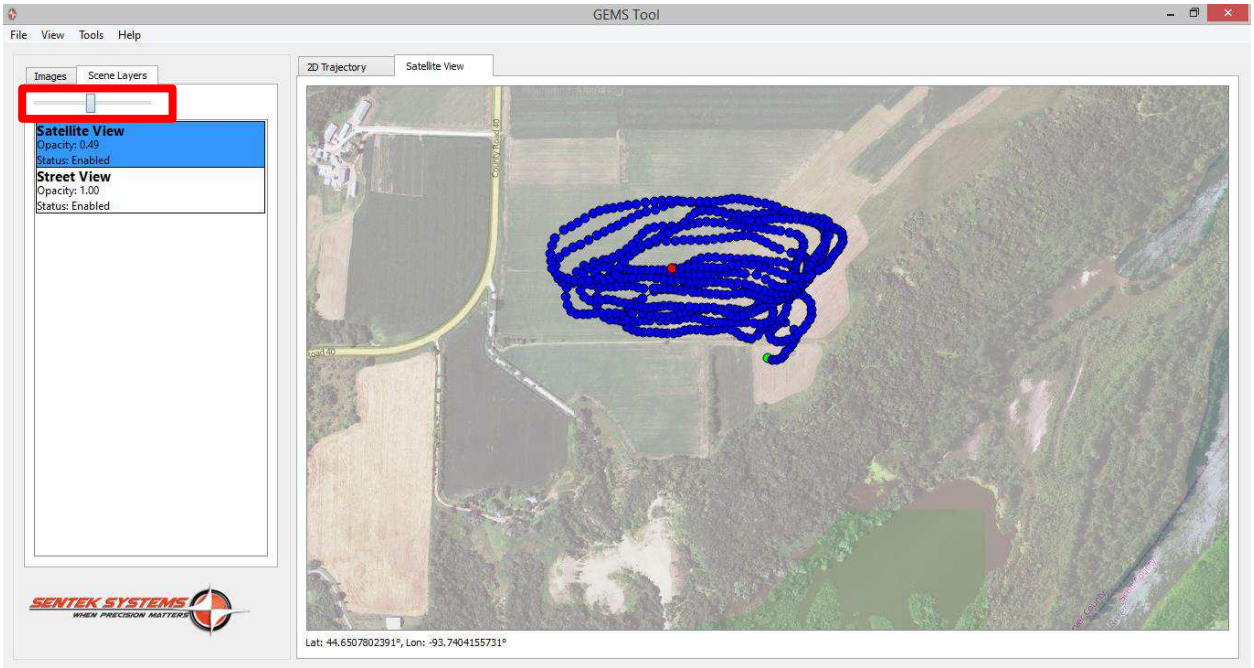


Figure 15 Slider in the middle indicating semi-transparent satellite imagery with street view

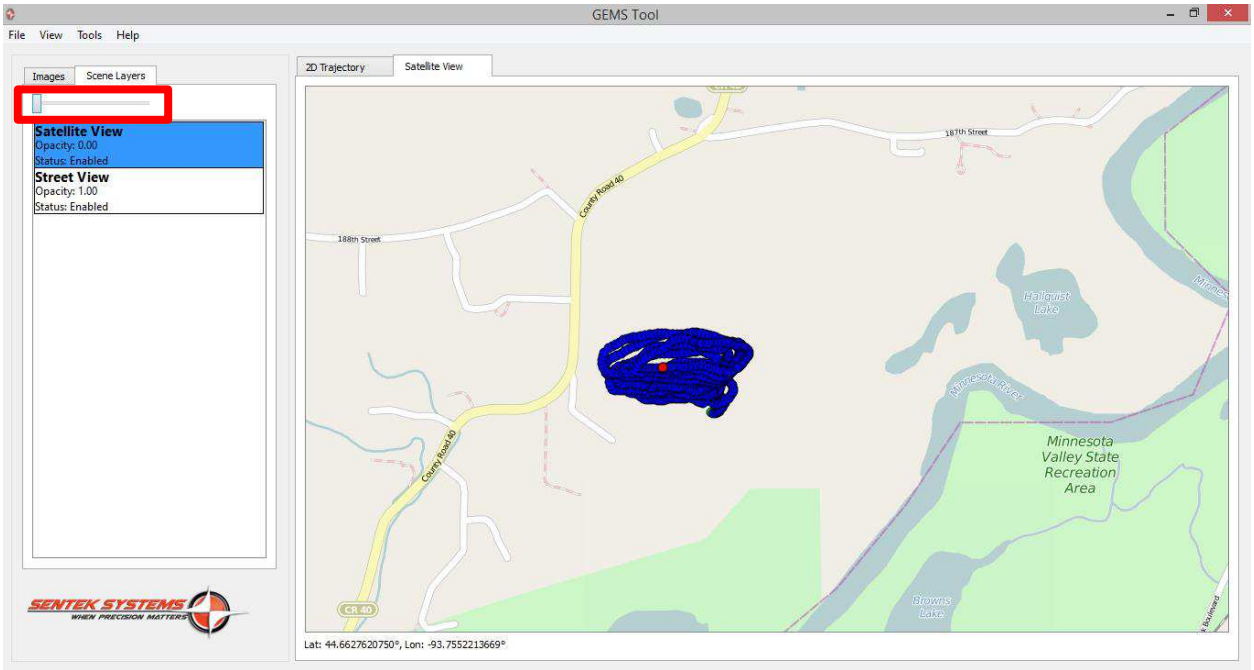


Figure 16 Slider to the left indicating street maps imagery in viewing window

4.4. Image Viewing Area & Tabs

The image viewing area is used to display all imagery. The default setting is to display the satellite imagery and the 2D trajectory imagery in tabs. Once sub-images have been selected and opened they are viewed as individual tabs. Any tile mosaic can be viewed in the viewing area by double clicking on the mosaic tile. It should be noted due to the large size of the mosaic tiles it is only recommended to view a single mosaic tile at one time.

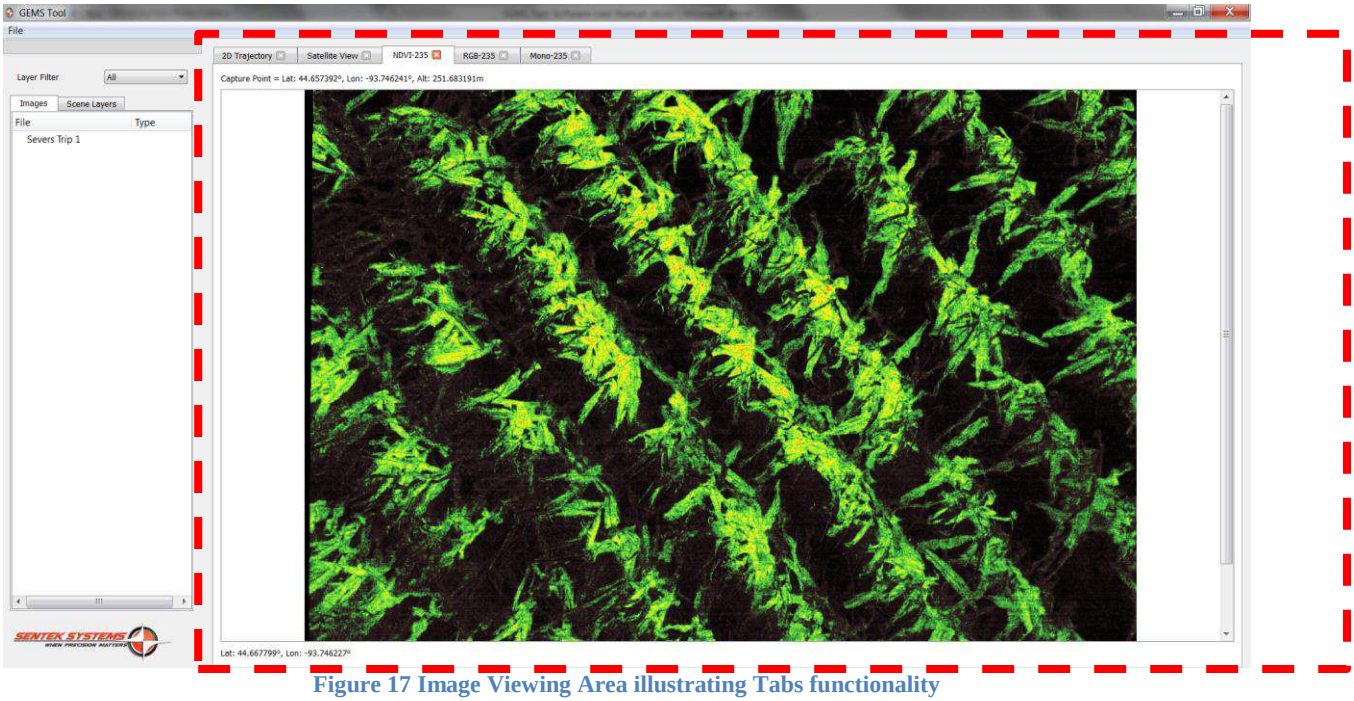


Figure 17 Image Viewing Area illustrating Tabs functionality

4.5. Run Modes for Data Generation

4.5.1. Run NDVI initialization

NDVI initialization is needed to perform the NDVI calculations. This step is typically 2-3mins and it is analyzing the imagery collected and performing spectral cross-band alignment. It is also selecting based on the imagery the best NDVI colormap configuration based on the statistics of the flight. NDVI initialization must be performed first to be able to enable any of the other run mode options described below. The user must select the Tools menu→Run NDVI initialization.

4.5.1.1. NDVI Colormap

The NDVI calculation allows for the user to allow the software to optimize the NDVI spectral colormap based on the flight characteristics. The default setting is selected to allow the software backend to optimize the NDVI per flight. By deselecting the Use Default Colormap checkbox the user has the ability to load a previously generated colormap. This enables the user to fly multiple times throughout the growing season and compare relative NDVI to each other with the same colormap settings. To save a colormap from a generated dataset the user would navigate on the menu to File→ Save Colormap→Name the file with a .stkcm file extension. To use this file for future NDVI colormaps then navigate to where this file was saved and load when prompted for the colormap on the individual Sub-images and the mosaics settings tabs. See Figures 18 & 19 below.

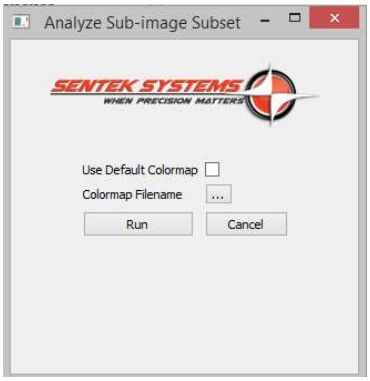


Figure 18 When running NDVI initialization or Sub-image NDVI the prompt for using default colormap or selecting a previously generated colormap will be created. The user should select default for the software to automatically optimize or de-select the check box and load a previously generated colormap.

Figure 19 When generating the mosaiced imagery the default setting that is selected is Use Default Colormap. If the user would like to use a previously saved colormap file de-select the default and navigate to the stored filename.

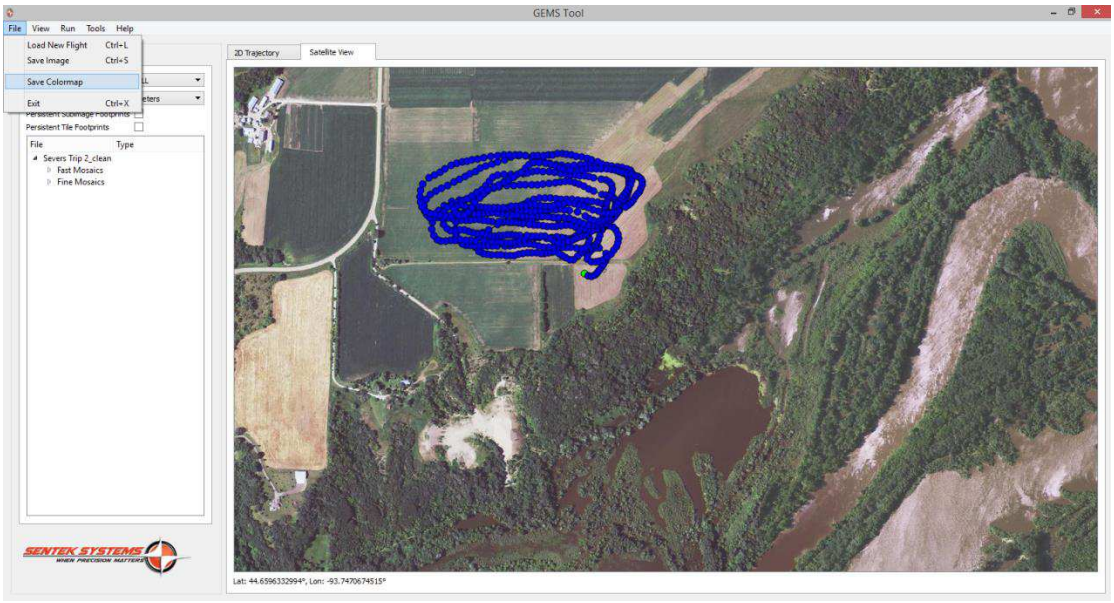


Figure 20 Once a flight dataset has been generated with sub-image NDVI and/or Mosaiced imagery NDVI the colormap can be stored and saved and loaded for future flights. To save the colormap use File→Save Colormap→Name the file with a .stkcm file extension.

4.5.2. Run NDVI on individual images at a time

NDVI for a single image can be obtained by selecting any of the blue camera trigger points as displayed in the satellite or 2D trajectories. Right click and select NDVI, the NDVI for this sub-image will appear in a new viewing tab. Once generated, the toggle on the top of the sub-image can easily be used to change between the NDVI, NIR, and RGB sub-images and GPS points of interest and the distance measurement tool can be used.

4.5.3. Generate All NDVI sub-images

After NDVI initialization, the user can run NDVI on all sub-images through selecting the Tools menu→Generate All NDVI Sub-images. Since this will be dependent on the flight duration (i.e. number of images taken) and the hardware running the GEMS Tool the time will vary. As an example, on a general i5 core intel CPU with no discrete GPU laptop for a 14 minute flight (628 image pairs) took about 10 minutes. On hardware with a discrete GPU on the same flight it took approximately 4 minutes.
Generate all NDVI sub-images can also be run immediately after loading the Flight Data.bin file without running the initialization and the processing time will increase slightly if this is done. This is the only run mode that can be run without the initialization step first.

4.5.4. Generate NDVI sub-image subset

After NDVI initialization, the user can run NDVI on a subset of images through selecting the Tools menu→Generate NDVI Sub-image Subset. A window appears to prompt the user to enter a starting image number and a total number of images and select run. This reduces the run time if a user has a specific region of interest in the field that they would like analyzed first.

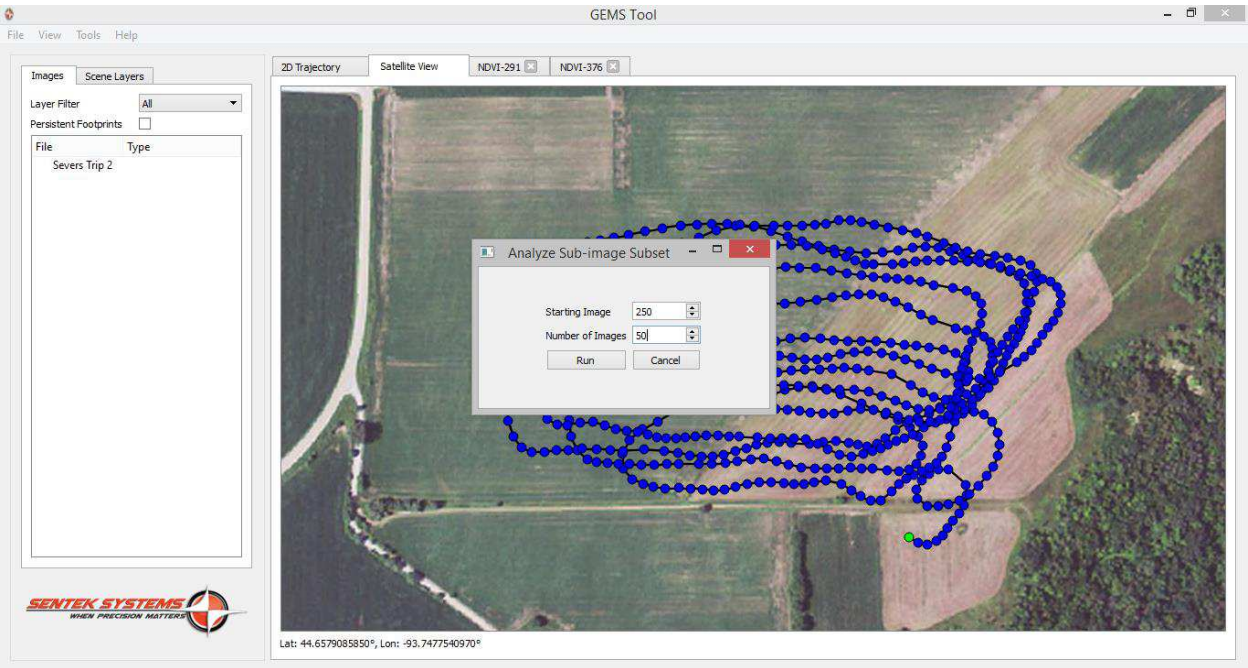


Figure 21 NDVI Sub-Image Subsets

4.5.5. Generate Mosaics

There are two run modes for the mosaicing feature:

(1) Fast mosaic

Fast mosaic throws the images acquired down as fast as it can given the predicted alignment based on the navigation data from the sensor payload.

(2) Fine mosaic

Fine mosaic performs additional computer vision image processing techniques to finely align the imagery which takes longer to process.

4.5.5.1. CPU versus GPU

The mosaic engine is setup so that the user can configure their system to run mosaics on their computer's CPU or GPU. The default is to run on the CPU but if the user selects "Use GPU Acceleration" the software is setup to auto scale the processing to the users GPU hardware on the end-user laptop. Therefore the user's hardware dictates the processing time and number of tiles generated. The more powerful the GPU the faster the processing time and the fewer mosaic tiles per dataset are generated. To open the mosaic tile double click on the Tile name in the file tree or right-click on it and select Open Tile.

Figure 22 Mosaic Default Settings

- Run→ Generate Mosaics
  - Default setting is Fast Mosaic (unchecked Fine Alignment)
  - Fast mosaic uses navigation data to generate a fast, coarsely aligned mosaic
  - Fine Alignment uses additional image processing to finely align mosaic but is more computationally intensive
  - NDVI unchecked only generates RGB and NIR mosaics
  - Default colormap allows the program to go through the sub-images and generate an optimized colormap scale.

5. Viewing Tabs

5.1. Flight Path Viewing: 2D Trajectory & Satellite Imagery

The 2D flight trajectory is output based on the onboard navigation and GPS subsystem. The route is plotted either on a grid background or on both the grid and satellite imagery. A blue dot illustrates the locations the cameras triggered and obtained an image. The green dot corresponds to the beginning of the flight and the red dot corresponds to the end of the flight. On the bottom left side of the screen in a toolbar the WGS-84 latitude (degrees) and longitude (degrees) are displayed. As the mouse moves across the screen the pixel geo-location coordinates are displayed. The grid spacing is also displayed for a relative reference.

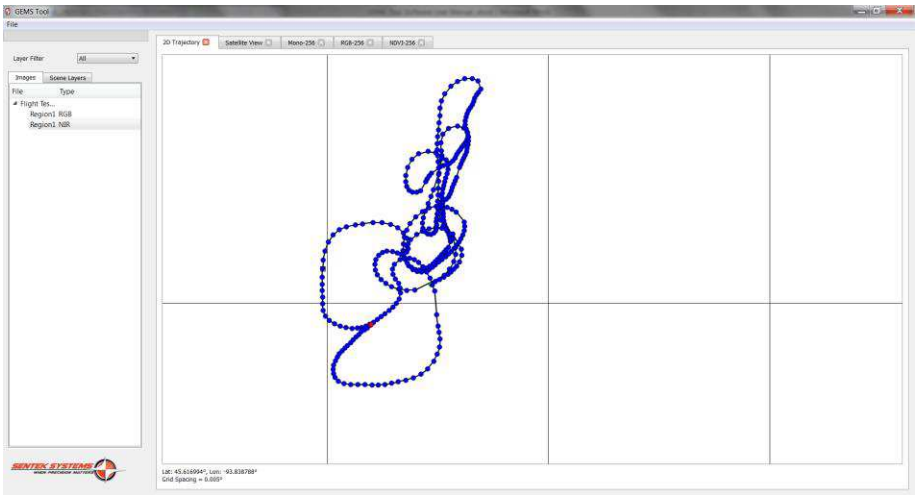


Figure 23 2D Trajectory is a default tab that populates every flight

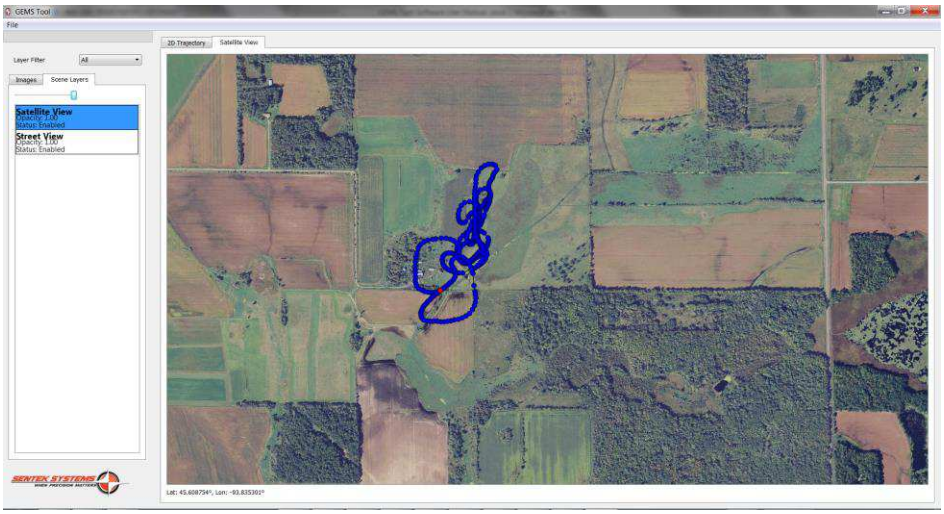


Figure 24 Satellite imagery is a default tab that populates if internet is available

5.1.1. 2D Footprints on ground

Since the GEMS is tightly coupled with the GPS/navigation system it automatically displays 2D footprints on the ground on both the satellite and 2D trajectory tabs. Hovering over a blue dot displays the 2D footprint on the ground of the image take at that location. This is utilized as a useful tool when viewing image overlap for the flight.

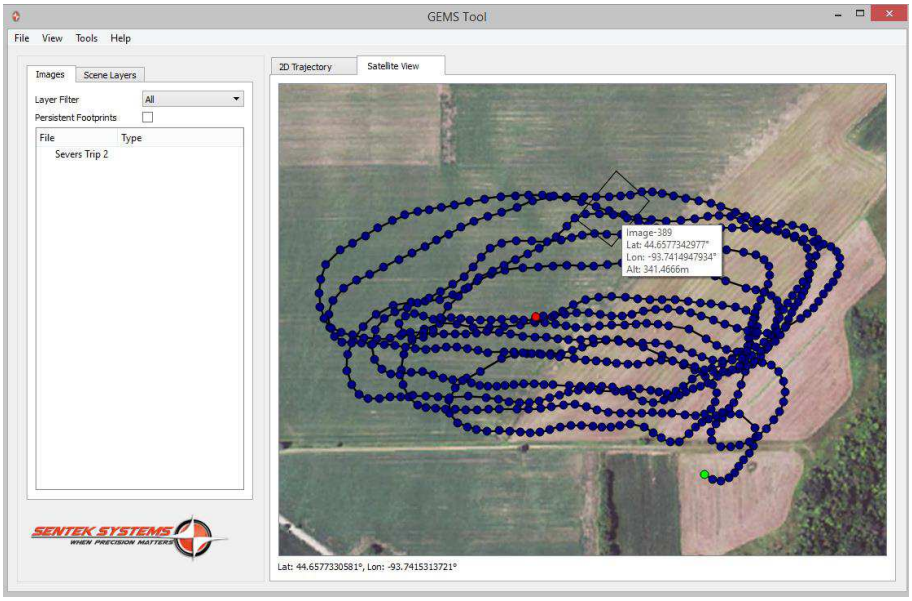


Figure 25 2D footprint of image capture

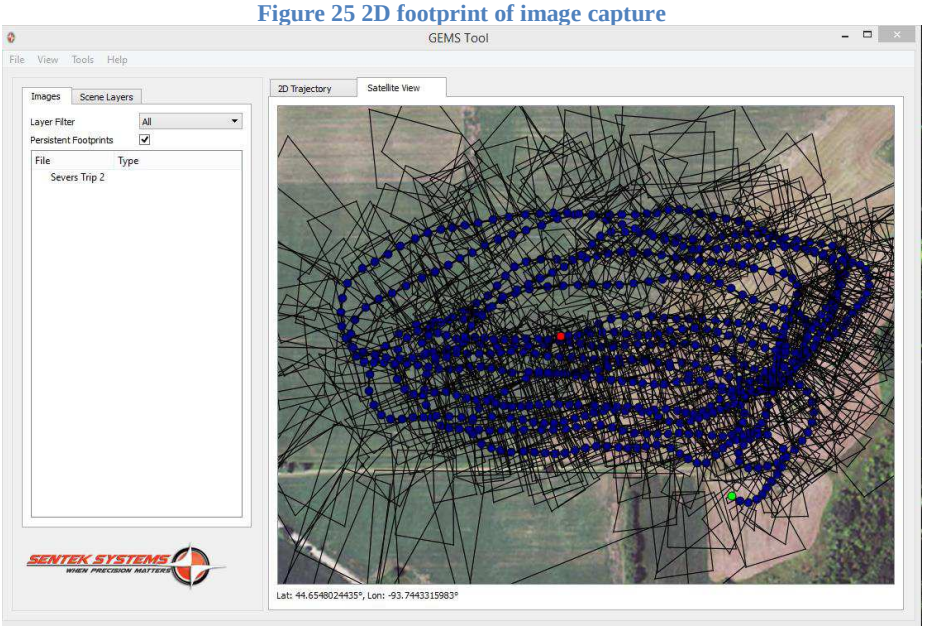


Figure 26 Persistent Footprints to view all overlap from flight

5.1.2. Geo-location for satellite imagery & 2D Trajectory

Geo-location information is available in both the satellite and 2D trajectory views. As the mouse hovers and moves across the screen the WGS84 latitude and longitude are displayed on the toolbar below the image.

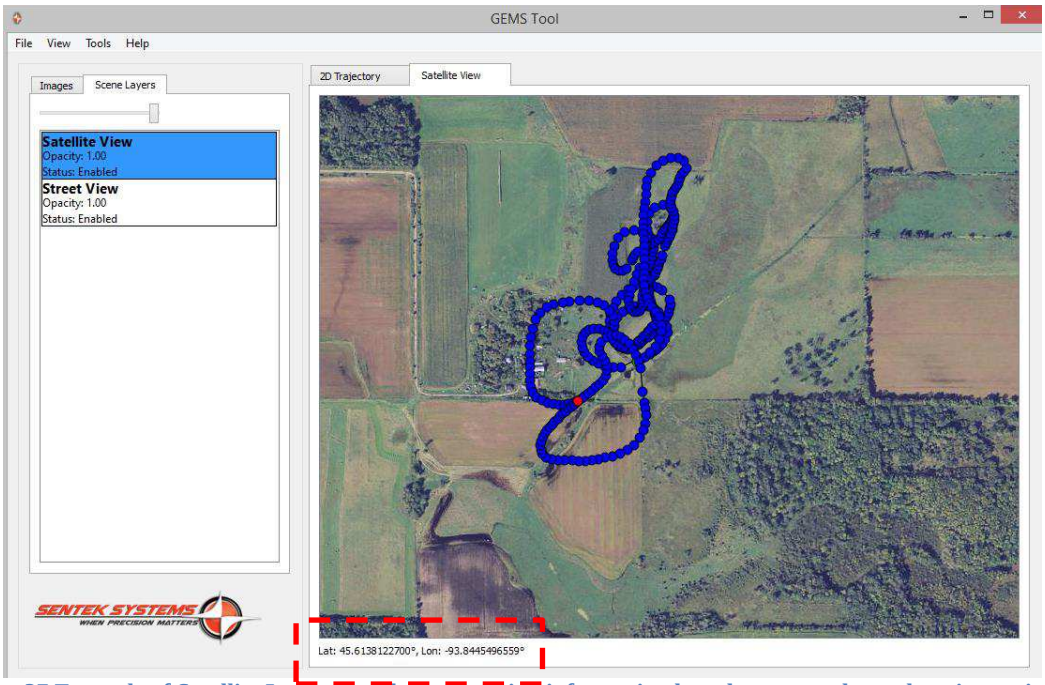


Figure 27 Example of Satellite Imagery with Geo-location information based on mouse hover location on image

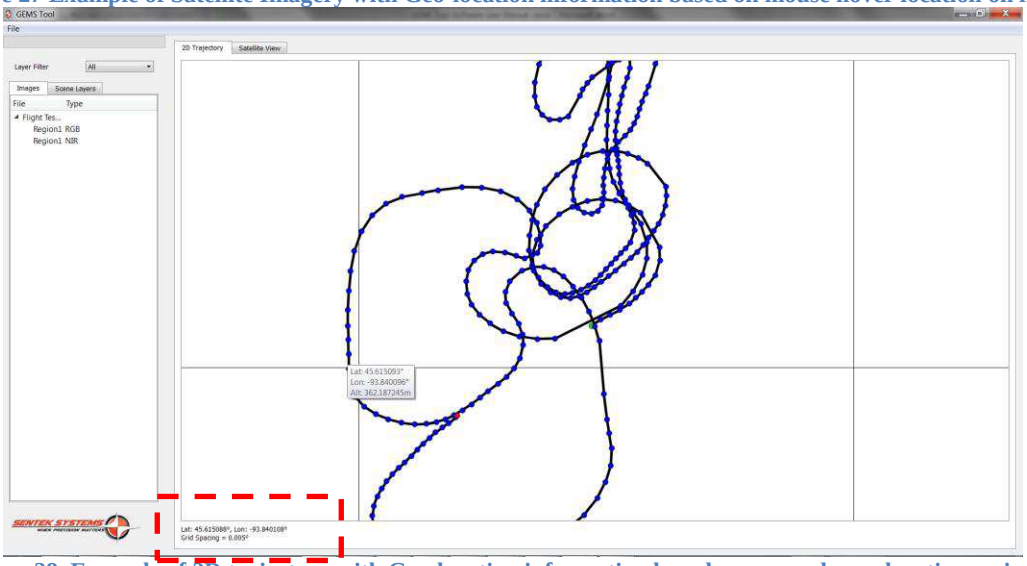


Figure 28 Example of 2D trajectory with Geo-location information based on mouse hover location on image

5.2. Sub-imagery from GEMS Hardware

The GEMS hardware platform simultaneously captures NIR and RGB images time synchronized to less than 1 millisecond with the inertial and GPS data. On the ground the GEMS Tool performs sub-pixel level cross band alignment and provides an NDVI image for every sub-image taken during flight. To view the RGB, NIR and NDVI sub-images, right click on any blue dot in either the satellite imagery or 2D trajectory tab.

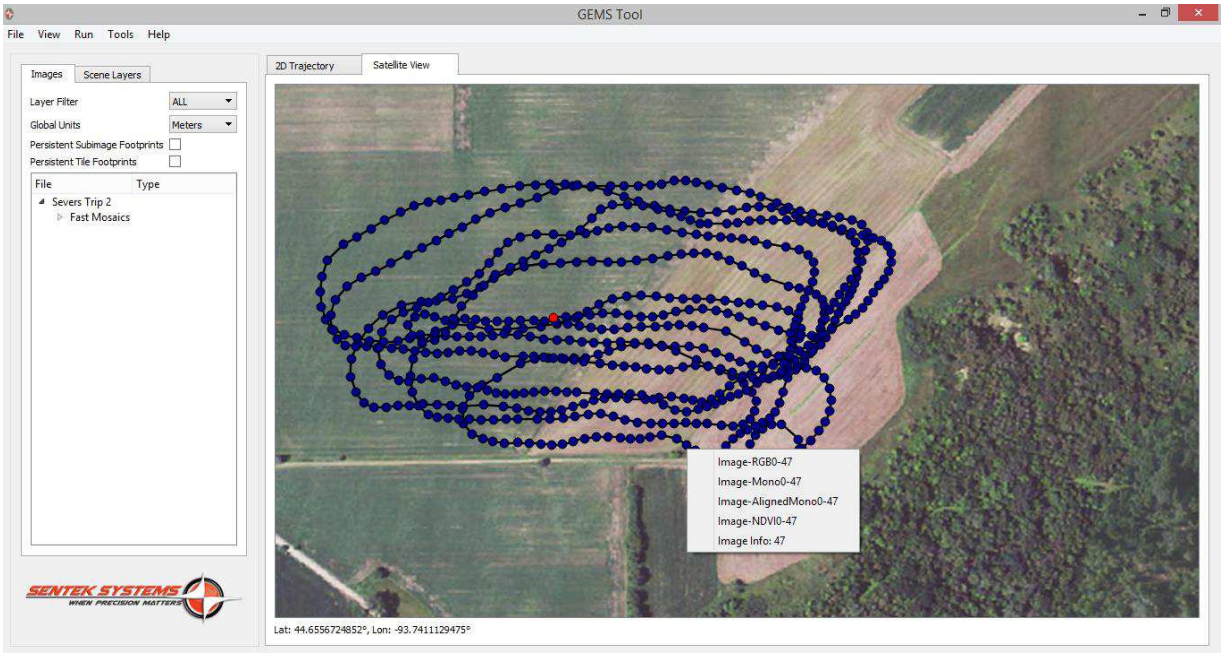


Figure 29 Illustrating right click functionality to open RGB, NIR, and NDVI sub-images.

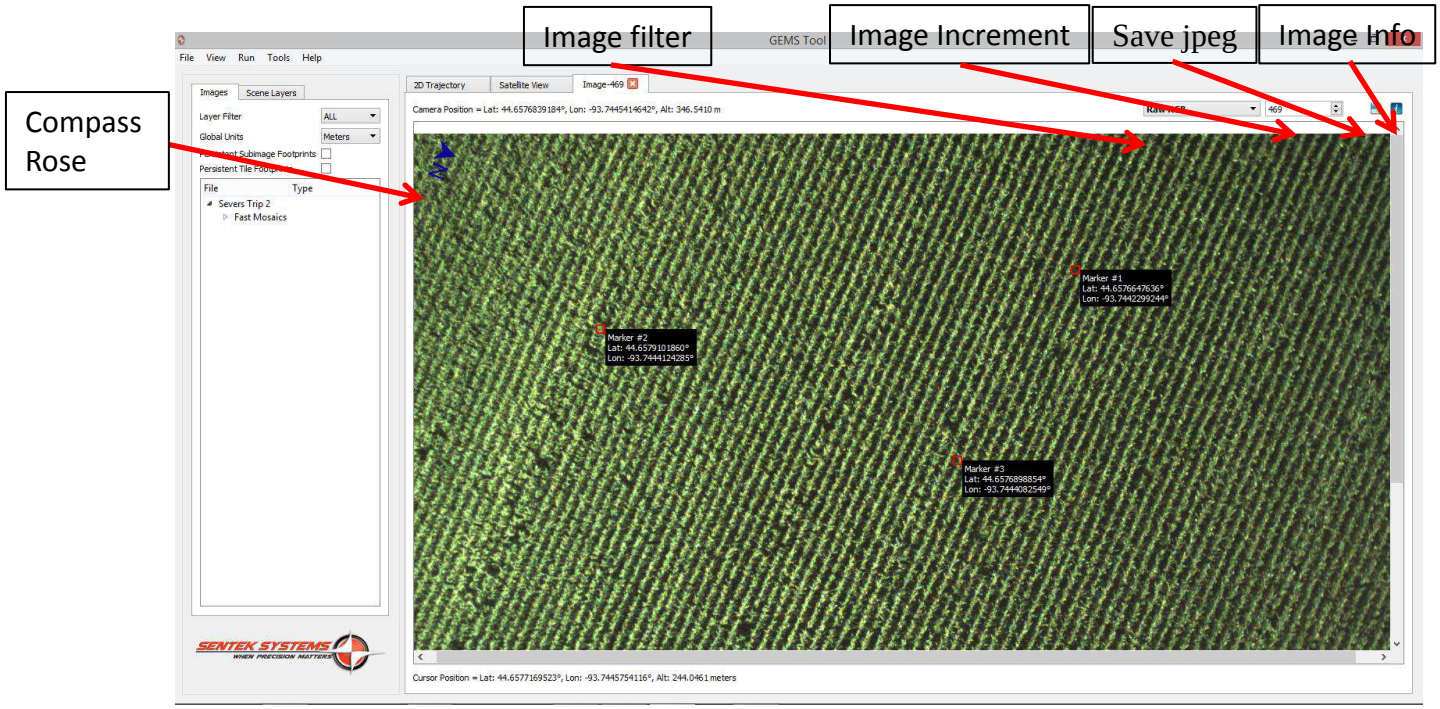


Figure 30 New GEMS 2.0 Features for Sub-images

- Compass Rose -helps users orient themselves with respect to the north
- All sub-images have zoom, pan, and scroll functionality by holding down the ctrl key and using the center mouse wheel scroll.
- Image filter type – enables toggling between RGB, NIR and NDVI images. Useful for analyzing the same location using different spectral bands and vegetation indices.
- Image increment – allows for quick toggling between different images to quickly flip through all images in a data set. If focus is in that widget, users can also toggle via up/down arrows
- Image Info provides all the collected inertial sensor, camera, and GPS data per sub-image. This is used to register imagery, form mosaics, optimize camera settings and exposure times, and export data to 3rd party software packages such as Pix4D.
- When GPS points of interest are placed on a sub-image (using ctrl left click) a save icon appears on the tab to allow the user to save the jpeg with the GPS points of interest overlaid. This can then be used for going back in the field to this same location for investigation.
- To reset the zoom on a sub-image double click the mouse on the sub-image and it will reset to zoomed out.

5.2.1. WGS84 Points of Interest

- The user can hold ctrl and left single click using the mouse on any object in any sub-image or mosaic to select a GPS "point of interest". Alternatively the user can use Tools→ Add Point and select on the sub-image the location to add the GPS marker.
- The WGS84 latitude, longitude, and marker number will be indicated.
- There is a filter at the top of each sub-image that allows the user to toggle between the spectrally aligned Mono (NIR), RGB, and NDVI sub-images with these selected GPS markers displayed.
- Points of interest can be cleared from the sub-images through the Tools pulldown menu→Clear Data→ Clear all points.
- The user can clear points from just a single sub-image by selecting Tools pulldown menu→Clear Data→ Clear points for sub-image.
- A single point of interest can be deleted from a sub-image by right clicking on the red box and selecting delete point.

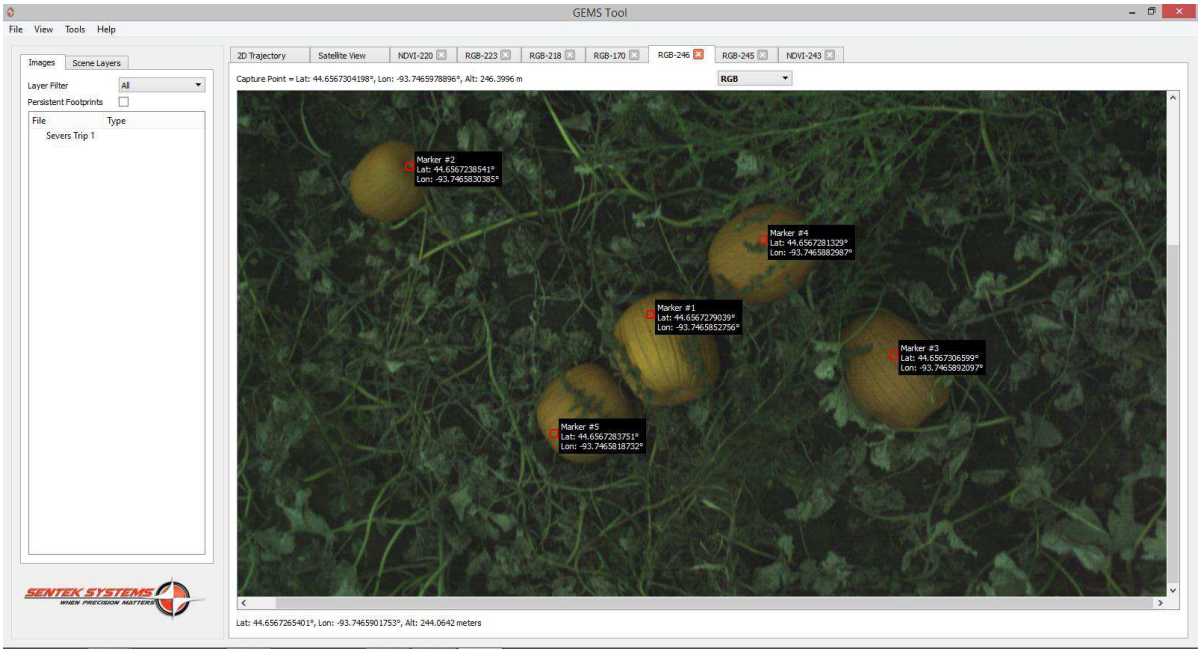


Figure 31 Left click on any point of interest and place marker

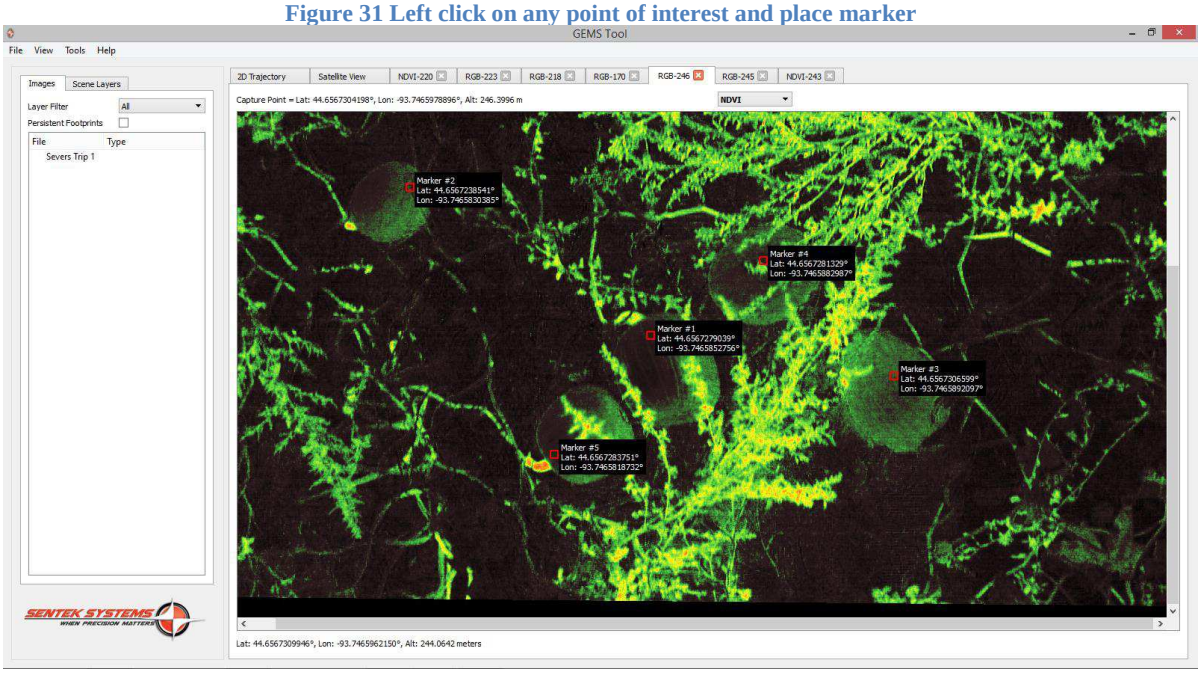


Figure 32 Same image as above of pumpkins but seen in NDVI. Illustrating spectrally aligned GPS markers.

5.2.2. Measurement Tool

- The user can activate the distance measurement tool by selecting the Tools pulldown menu→Measuring Tools→ Distance Tool or by pressing a hotkey. Hit D on the keyboard and select 2 points in the sub-image that you would like the distance between. The

displacements in the east and north directions and the heading to move from point 1 to point 2 are displayed.

- You can change or set the global units preference for the distance tool by using the navigation tree global units.
- Default is meters but if changed to feet all the distance measurement labels will change to feet.
- The distance measurement tool has tick marks on it, the smaller ticks are for 30 " and the larger ticks are for 17.5'.
- To activate the ruler on all sub-images go to Tools→ Measuring Tools → Show Ruler
- All measurements from all the sub-images can be cleared by selecting the Tools pulldown menu→Clear Data→ Clear All Measurements.
- Measurements can be cleared from each individual sub-image by selecting the Tools pulldown menu→Clear Data→ Clear Measurements for Sub-image.
- A single measurement can be deleted by right clicking on the first blue box and deleting point.

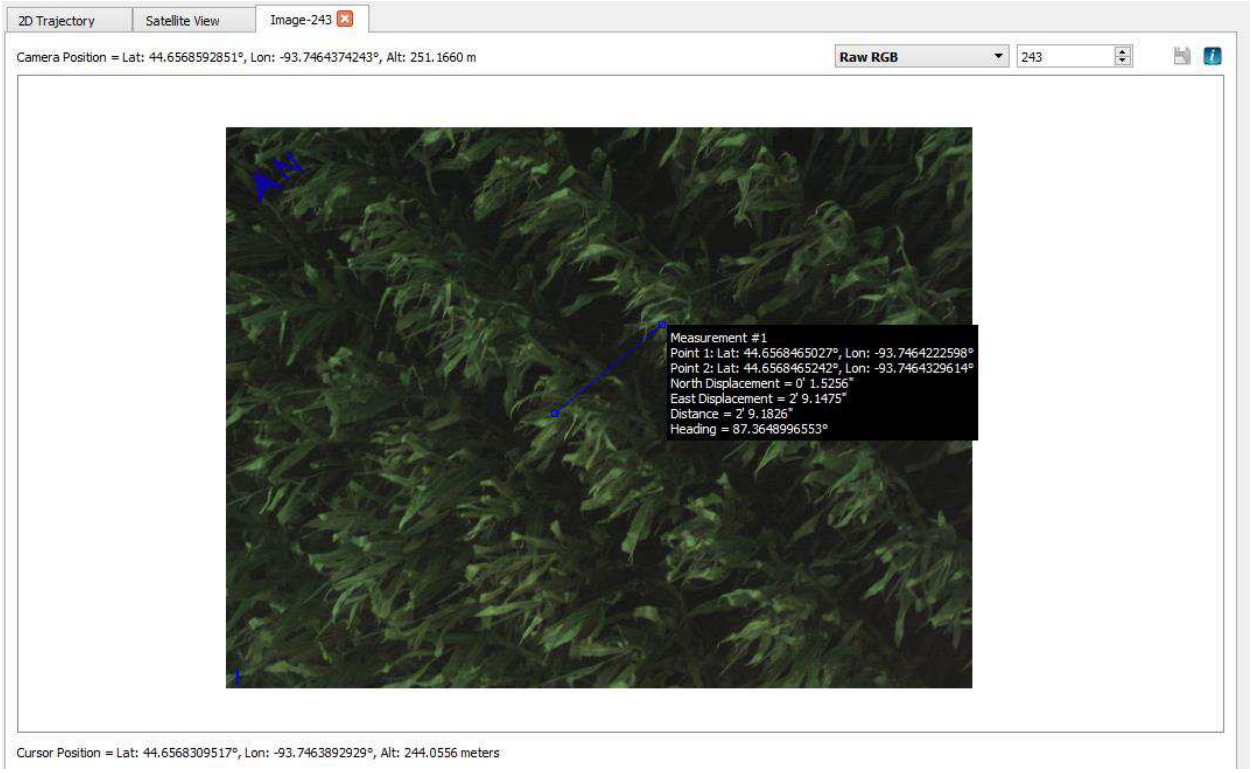

2D Trajectory
Satellite View
Image-243
Camera Position = Lat: 44.6568592851°, Lon: -93.7464374243°, Alt: 251.1660 m
Raw RGB
243
Measurement #1
Point 1: Lat: 44.6568465027°, Lon: -93.7464222598°
Point 2: Lat: 44.6568465242°, Lon: -93.7464329614°
North Displacement = 0' 1.5256"
East Displacement = 2' 9.1475"
Distance = 2' 9.1826"
Heading = 87.3648996553°
Cursor Position = Lat: 44.6568309517°, Lon: -93.7463892929°, Alt: 244.0556 meters

Figure 33 Example using distance measuring tool to measure distance between rows of corn.

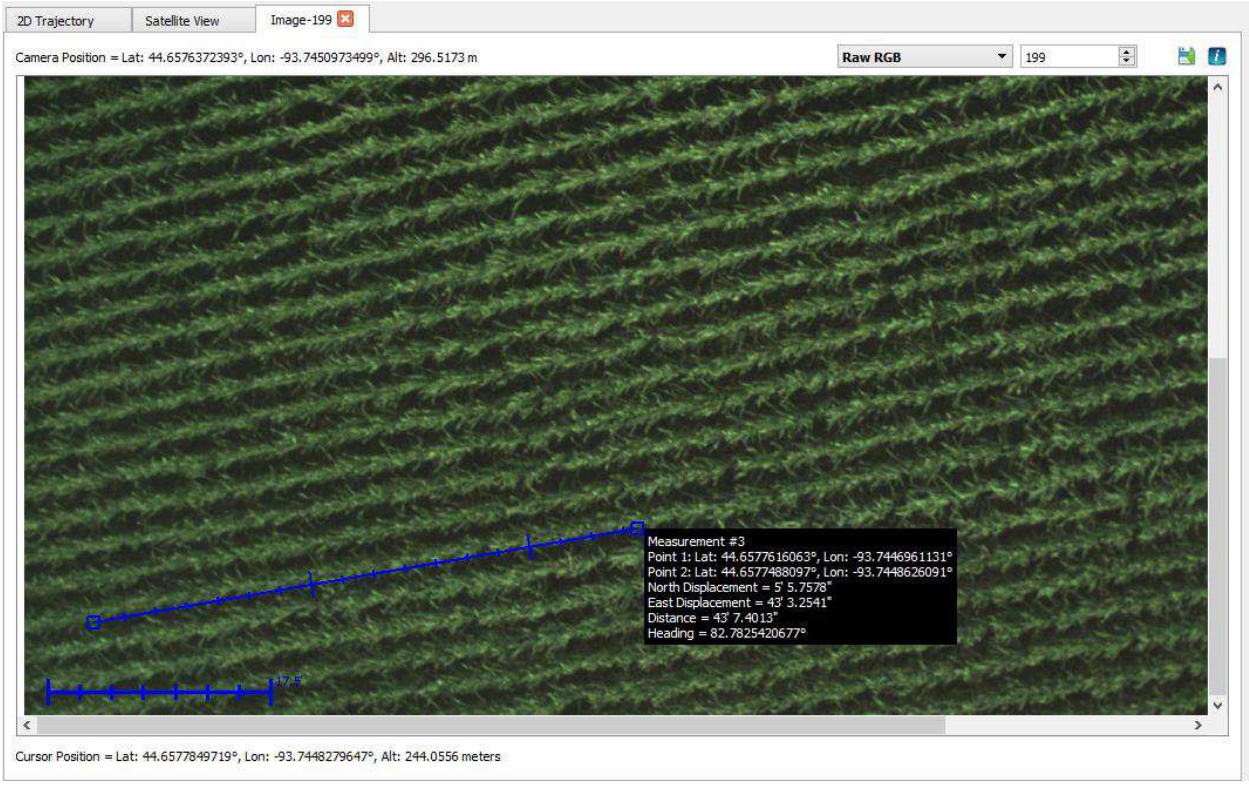

2D Trajectory
Satellite View
Image-199
Camera Position = Lat: 44.6576372393°, Lon: -93.7450973499°, Alt: 296.5173 m
Raw RGB
199
Measurement #3
Point 1: Lat: 44.6577616063°, Lon: -93.7446961131°
Point 2: Lat: 44.6577488097°, Lon: -93.7448626091°
North Displacement = 5' 5.7578"
East Displacement = 43' 3.2541"
Distance = 43' 7.4013"
Heading = 82.7825420677°
Cursor Position = Lat: 44.6577849719°, Lon: -93.7448279647°, Alt: 244.0556 meters

Figure 34 Example showing ruler on bottom left of sub-image with the distance measurement tool with tick marks.

5.2.3. Geo-location for individual sub-images

- Geo-location information for all sub-images (RGB, NIR, and NDVI) is available. As the mouse hovers and moves across the screen the WGS84 latitude and longitude are displayed on the toolbar below the image.

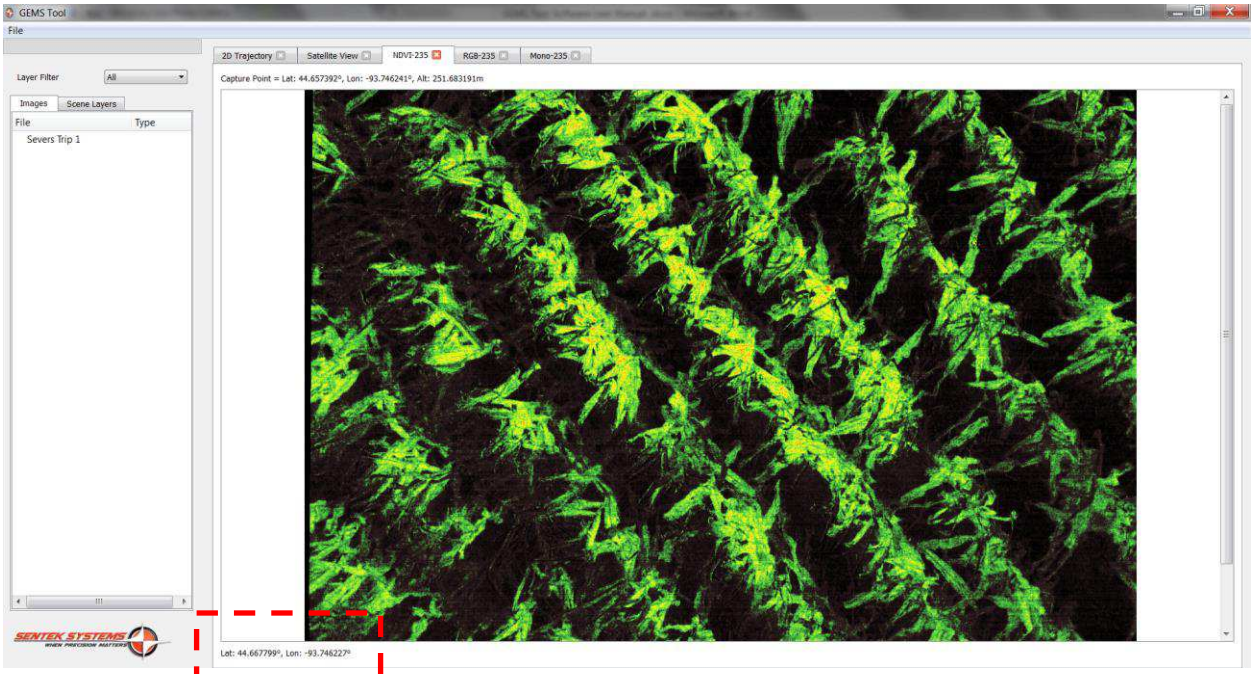


Figure 35 Example of NDVI Sub-image with Geo-location information based on mouse hover location on image

5.2.4. Exporting Points of Interest and Measurement Distances

- For all sub-images and mosaics (RGB, NIR, and NDVI) the WGS84 points of interest can be exported to a CSV file by selecting the Tools pulldown menu→Export Data→ Export Points to File.
- For all sub-images (RGB, NIR, and NDVI) the distance measurements can be exported to a CSV file by selecting the Tools pulldown menu→Export Data→ Export Measurements to File.

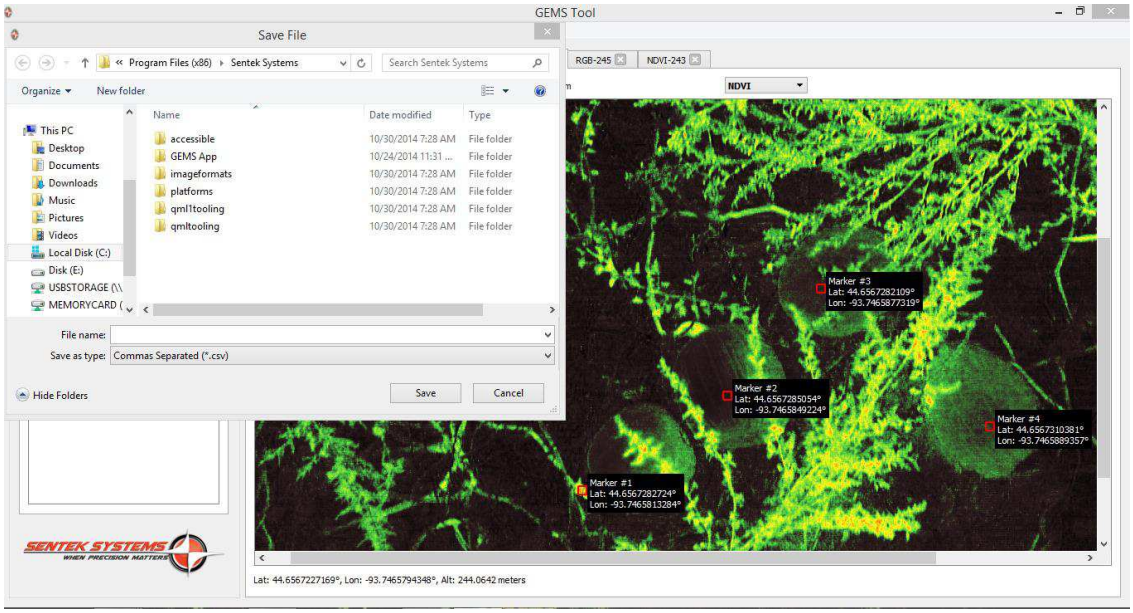
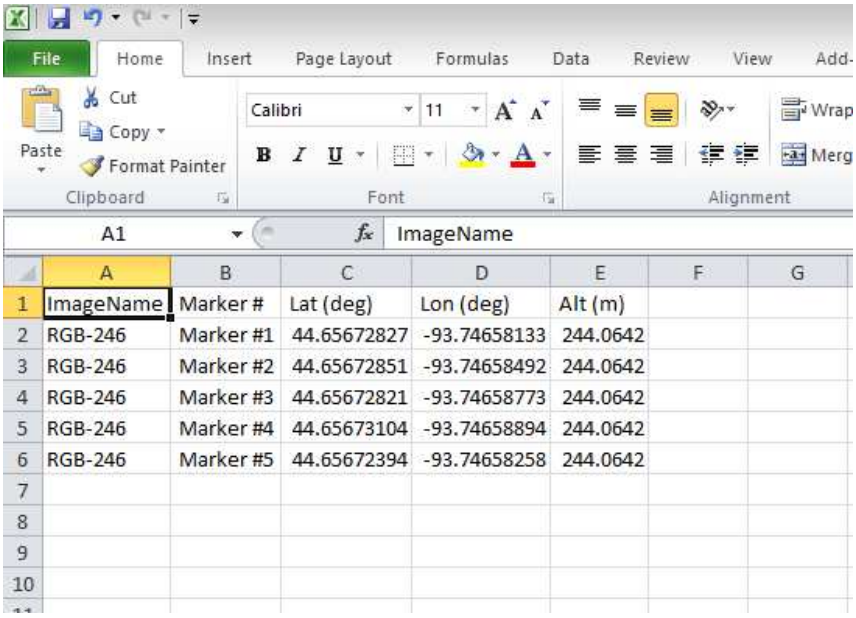
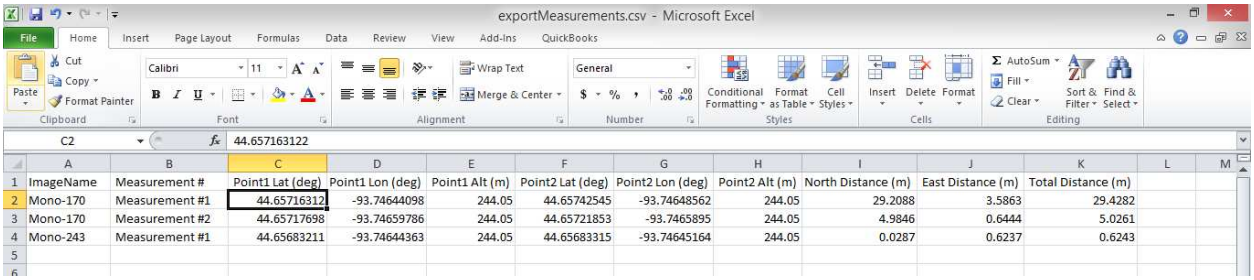


Figure 36 Prompt to save the filename and location on computer as CSV file format



	A	B	C	D	E
1	ImageName	Marker #	Lat (deg)	Lon (deg)	Alt (m)
2	RGB-246	Marker #1	44.65672827	-93.74658133	244.0642
3	RGB-246	Marker #2	44.65672851	-93.74658492	244.0642
4	RGB-246	Marker #3	44.65672821	-93.74658773	244.0642
5	RGB-246	Marker #4	44.65673104	-93.74658894	244.0642
6	RGB-246	Marker #5	44.65672394	-93.74658258	244.0642

Figure 37 Example of File Format exported to CSV for WGS84 Points of Interest



	A	B	C	D	E	F	G	H	I	J	K
1	ImageName	Measurement #	Point1 Lat (deg)	Point1 Lon (deg)	Point1 Alt (m)	Point2 Lat (deg)	Point2 Lon (deg)	Point2 Alt (m)	North Distance (m)	East Distance (m)	Total Distance (m)
2	Mono-170	Measurement #1	44.65716312	-93.74644098	244.05	44.65742545	-93.74648562	244.05	29.2088	3.5863	29.4282
3	Mono-170	Measurement #2	44.65717698	-93.74659786	244.05	44.65721853	-93.7465895	244.05	4.9846	0.6444	5.0261
4	Mono-243	Measurement #1	44.65683211	-93.74644363	244.05	44.65683315	-93.74645164	244.05	0.0287	0.6237	0.6243

Figure 38 Example of File Format exported to CSV for Measurements

5.3. Mosaic Tiles

Mosaiced tiles are populated in the navigation tree along with the mosaic overviews. The overviews are used to generate a “bird’s eye view” of the imagery which combines the tiles into one larger image.

Mosaic Overview Tile functionality:

- Double click the tile in the left-hand navigation tree for a new viewing tab to open.
- Pan, zoom, and scroll capability
- To reset zoom on the mosaic tile double click in the tile viewing tab.

Mosaic Tile functionality:

- Double click the tile in the left-hand navigation tree for a new viewing tab to open.
- Pan, zoom in, and scroll capabilities exist on all mosaiced tiles
- Geo-location exists on all mosaiced tiles with the movement of the mouse cursor
- The layer filter on the tile viewer filters between the tile RGB, NIR, NDVI images for each tile

- If more than one tile is generated the user can increment through the tiles in the tile viewer.
- All GPS markers "Points of Interest" can be placed on mosaic tiles the same as sub-images (hold ctrl and left click on mouse or through Tools→Add Point)
- All Distance measurements can be performed on tiles similar to sub-images (press D hotkey and select two locations or Tools→Measuring Tools→Distance Tool)
- To reset zoom on the mosaic tile double click in the tile viewing tab.

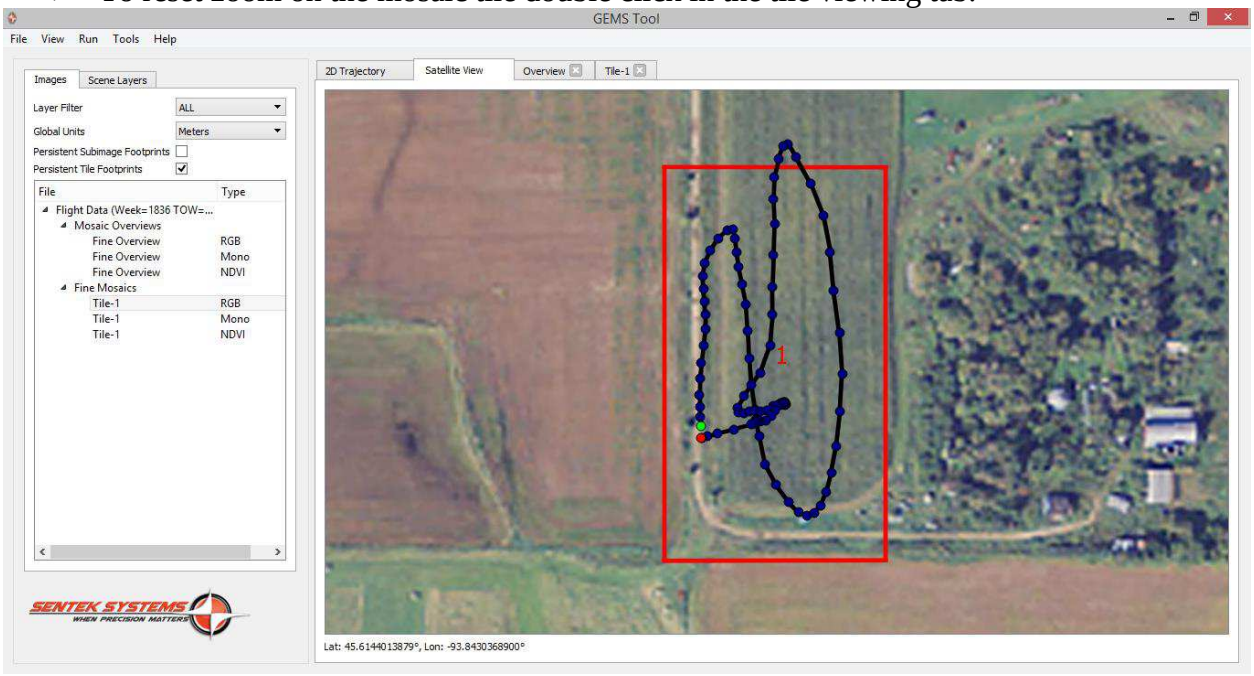


Figure 39 Example Persistent Footprints on Satellite Imagery

Figure 40 Example RGB Mosaic Overview Tile showing "Bird's Eye View" of field

Figure 41 Example RGB Mosaic Tile with distance measurement and GPS points of interest

6. Export to Pix4D

Some users would like 3D reconstructions and so GEMS supports export to other tools that provide this analysis. Since GEMS provides very accurately time-stamped imagery and camera positions and orientation at the instant each image is triggered it is able to seamlessly export data in the format needed by these feature based reconstruction tools.

- Tools →Export Data → Export to Pix4D
- Generates CSV files with image name, Lat , Lon, Alt, Omega, Phi, Kappa
- 4 files are saved to the Export sub-folder in the current flight data folder: 1 for RGB images, 1 for NIR images, 1 for NDVI-FC1 images, and 1 for NDVI-FC2 images.

7. Export to SMS

SMS is a popular Farm Management tool which interfaces with multiple different farm equipment and measurement devices. It allows farmers or crop consultants to overlay geo-referenced layer maps (i.e. soil maps, yield maps, historical maps), create prescriptions, print detailed reports and analyze yields. Through the GEMS software the user can output the NDVI values from the GEMS UAV imagery that was collected and generates a CSV file with the correct file format needed to import this UAV NDVI imagery into SMS for prescription maps on a 1 meter resolution.

- Tools →Export Data → Export to SMS
- Generates a CSV file called NDVI_Measurements_SMS.csv that is stored in the Flight Data Folder in a Sub-folder called Export

- For explicit directions on how to read GEMS generated CSV into SMS for the NDVI layer refer to Appendix B.

8. Launch PowerOfGround

PowerOfground is a cloud GIS software platform that the GEMS software integrates with for multiple additional processing capabilities. Through the Tools pulldown menu there is Launch PowerOfGround which will bring the user to a login page, a registration page, or an upload page. The GEMS user has the ability to export the final RGB, NIR, or NDVI geo-tiff format mosaics for cloud archival services or they can through the PowerOfGround wizard upload the POG-RGB.txt and POG-NIR.txt generated by GEMS software and the Flight Data sub-images. PowerOfGround utilizes 3D reconstruction 3rd party software 3D reconstruction, volumetric analysis, and additional spectral processing for a per time fee. Any PowerOfGround processing is performed under the user contract with PowerOfGround; Sentek Systems provides the ability to integrate with these additional services and the GEMS provides the geo-referenced imagery.

9. Files Automatically Generated through GEMS GUI

Once the GUI opens and the FlightData.bin file is loaded into the GEMS Tool, in the background the software will automatically generate two files: (1) Metadata.txt and (2) ImInfo.txt corresponding to this flight. These files are automatically stored in the current working folder corresponding to the flight. The GEMS software tool is designed such that the user should never need to see this information, however, some advanced users would like access to this for additional applications.

In release 2.1.2 additional file formats are automatically generated once the GEMS software processing has been performed these include: (1) NDVI False Colormap 1 (NDVI-FC1), (2) NDVI False Colormap 2 (NDVI-FC2), (3) NDVI False Colormap Mono (NDVI-Mono), and (4) Geo-tiffs of the Overview Mosaics. Each will be further described in sub-sections below.
The file structure is illustrated below. Prior to running GEMS software the Flight Data Folder will only be populated with raw imagery, calibration files, and metadata files (FlightData.bin).

After processing the NDVI sub-images, the tool will automatically create folders for each type of data generated. The different NDVI false colormaps will each have their own sub-folder and the mosaics and mosaiced tiles will have a sub-folder labeled Tiles.

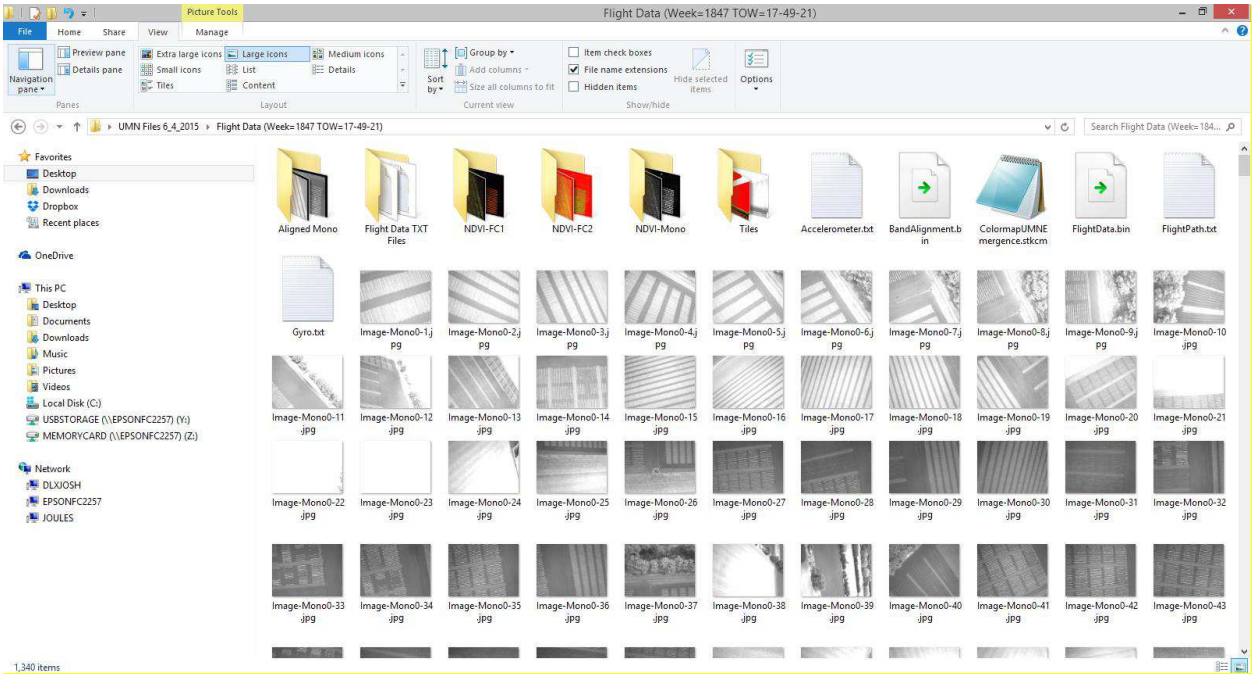


Figure 42 Example of Windows browser where the automatically generated sub-folders appear in the Flight Data Folder

9.1. RawImageMetadata.txt

The RawImageMetadata.txt file is stored in the same folder as the raw imagery in the main folder. The Metadata.txt structure format is as follows:

Field Name	Definition
Image Number	Number of image acquisition event (matches number in raw image filenames)
camLat	Camera latitude in decimal degrees
camLon	Camera longitude in decimal degrees
camAlt	Camera altitude in meters
yaw	Camera yaw in decimal degrees
pitch	Camera pitch in decimal degrees
roll	Camera roll in decimal degrees
Thinsetmember	Thin dataset member. 0 if not a member of the thinned dataset. 1 if the image is a member of the thinned dataset. The thinned dataset is a thinned out collection of imagery that still provides sufficient image overlap on the ground for mosaicing.
Lat0	Latitude (decimal degrees) of lower left corner of image
Lon0	Longitude (decimal degrees) of lower left corner of image
Alt0	Altitude (meters) of lower left corner of image
Lat1	Latitude (decimal degrees) of lower right corner of image
Lon1	Longitude (decimal degrees) of lower right corner of image
Alt1	Altitude (meters) of lower right corner of image

Lat2	Latitude (decimal degrees) of upper right corner of image
Lon2	Longitude (decimal degrees) of upper right corner of image
Alt2	Altitude (meters) of upper right corner of image
Lat3	Latitude (decimal degrees) of upper left corner of image
Lon3	Longitude (decimal degrees) of upper left corner of image
Alt3	Altitude (meters) of lower left upper of image

Figure 43 RawImageMetadata.txt structure format. Latitude, Longitude, and Altitude are in WGS84.

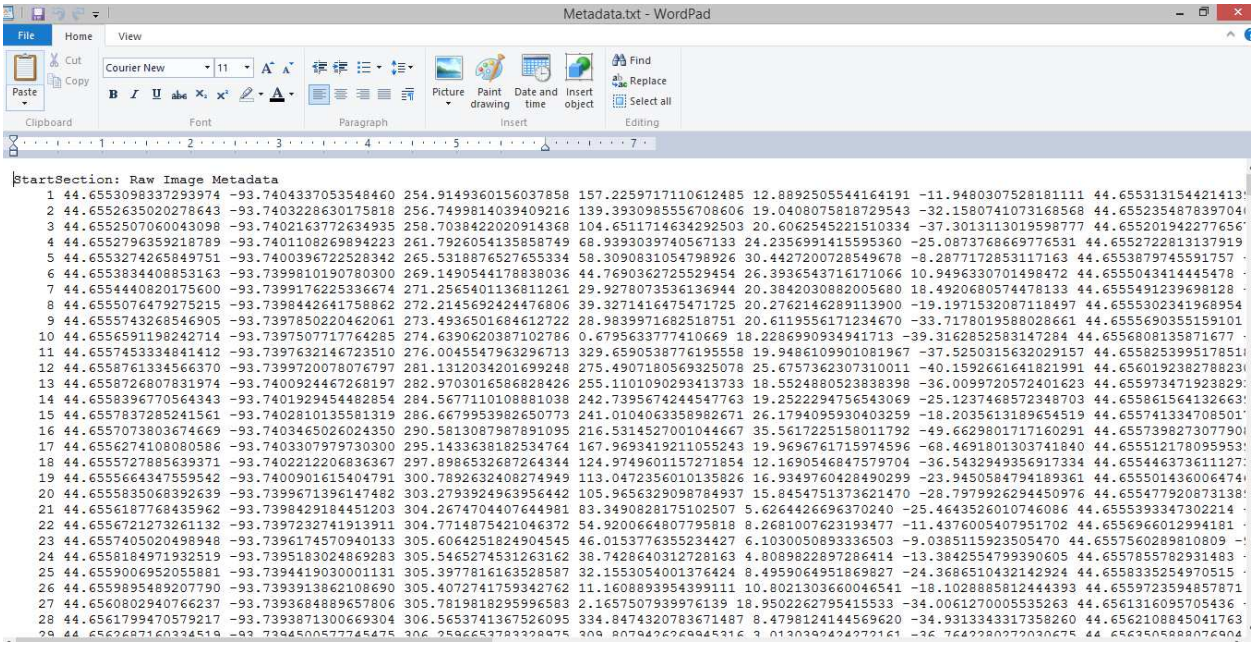
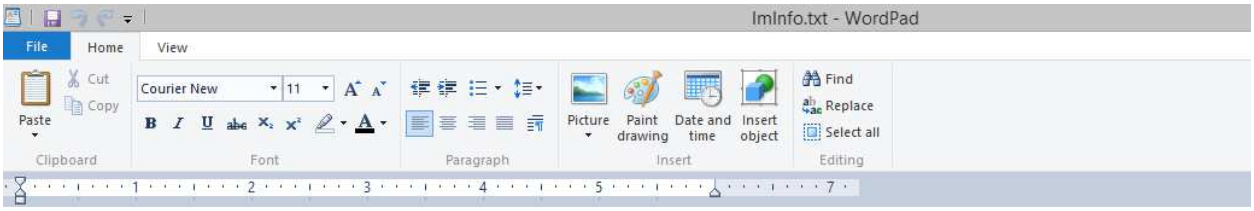


Figure 44 Example of RawImageMetadata.txt file generated automatically

9.2.ImInfo.txt

The Image information file can be extremely useful to users for image analysis. The GUI automatically generates it in the background and stores it one level down from the main flight folder in a subfolder called Flight Data TXT Files. For each image pair that is captured, the GEMS system records key camera parameters. These parameters include: camera position (lat, lon, alt), System attitude (yaw, pitch, roll), Height above ground, Speed, GSD, and RGB/NIR camera data (exposure duration, distance traveled during exposure, exposure time, smearing).




```
           Translation-based smearing = 0.230008 pixels

Image Number: 35
Camera Position: Lat = 44.656060 deg, Lon = -93.739989 deg, Alt = 304.339676 m (998.489783 ft)
System Attitude: Yaw = 211.378329 deg, Pitch = 8.018584 deg, Roll = 15.577791 deg
Height above ground = 60.343535 m (197.977483 ft)
Speed = 12.368515 m/s (27.667625 mph)
GSD =  2.9387 cm ( 1.1570 inches)
RGB Info:  Exposure = 1.000000 ms
           Distance Traveled During Exposure = 1.236851 cm
           Translation-based smearing = 0.420886 pixels
Mono Info: Exposure: 0.541000 ms
           Distance Traveled During Exposure = 0.669137 cm
           Translation-based smearing = 0.227700 pixels

Image Number: 36
Camera Position: Lat = 44.655983 deg, Lon = -93.740040 deg, Alt = 305.450217 m (1002.133289 ft)
System Attitude: Yaw = 223.878543 deg, Pitch = 8.383227 deg, Roll = 26.589062 deg
Height above ground = 61.454075 m (201.620988 ft)
Speed = 11.867647 m/s (26.547214 mph)
GSD =  2.9928 cm ( 1.1783 inches)
RGB Info:  Exposure = 1.000000 ms
           Distance Traveled During Exposure = 1.186765 cm
           Translation-based smearing = 0.396545 pixels
Mono Info: Exposure: 0.541000 ms
           Distance Traveled During Exposure = 0.642040 cm
           Translation-based smearing = 0.214531 pixels

Image Number: 37
Camera Position: Lat = 44.655927 deg, Lon = -93.740111 deg, Alt = 306.984298 m (1007.166365 ft)
System Attitude: Yaw = 232.477118 deg, Pitch = 9.688475 deg, Roll = 27.897856 deg
```

Figure 45 Example of ImInfo.txt file generated automatically

9.3. NDVI-FC1

Similar to prior releases of the GEMS software, once the Run NDVI initialization has been run in the graphical user interface, and NDVI sub-images have been generated, a new folder labeled (NDVI-FC1) is created for these post-processed images in the current Flight Data Folder. The NDVI False Colormap 1 (NDVI-FC1) is relative NDVI where black is for min NDVI and red is for max NDVI.

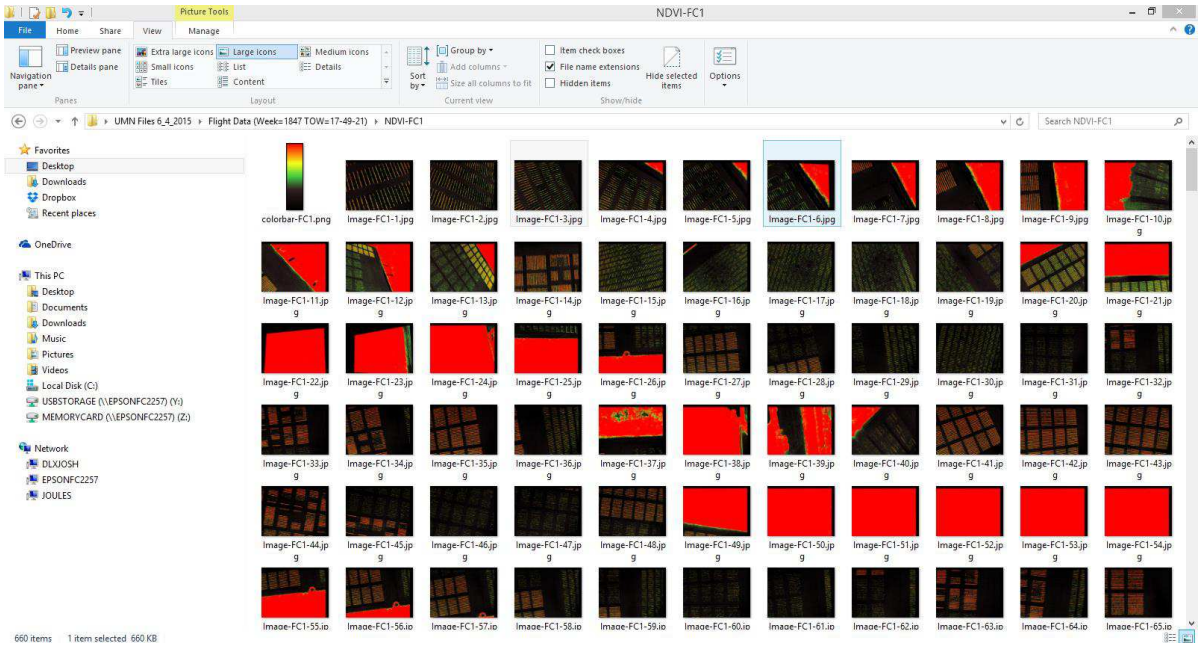


Figure 46 Example of Windows Browser NDVI Sub-images Directory for NDVI-FC1

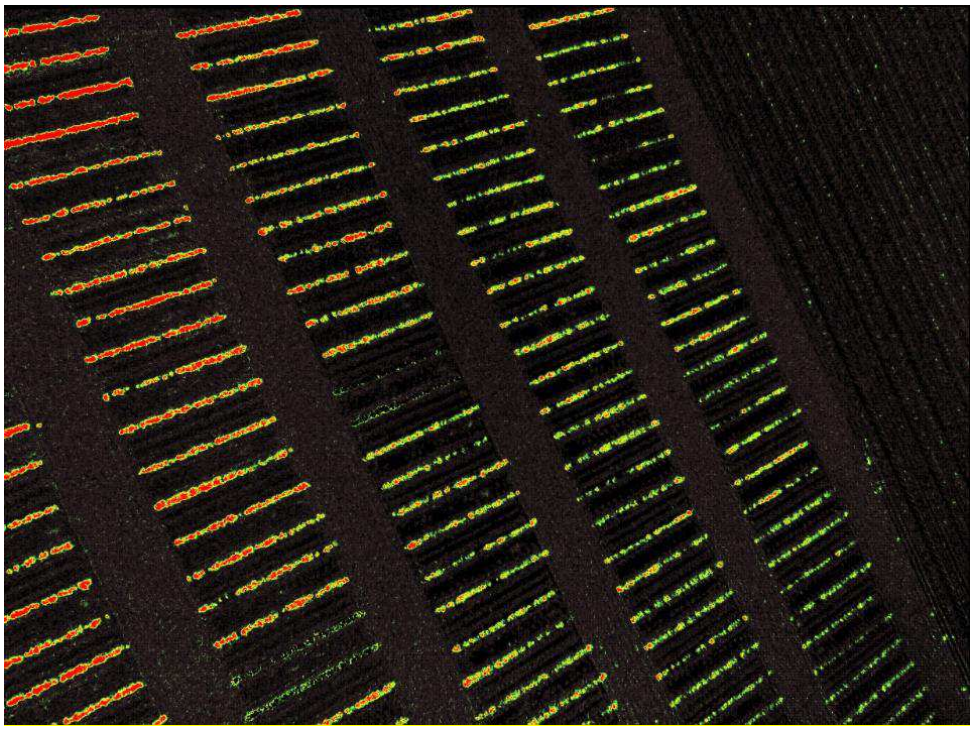


Figure 47 Example of NDVI False Colormap 1 (min NDVI Black, max NDVI Red)

9.4.NDVI-FC2

In release 2.1.2 a new NDVI colormap has been added. When running the NDVI initialization and NDVI sub-image processing exactly the same way as FC1 above, a new folder labeled (NDVI-FC2) is created for the post-processed images in the current Flight Data Folder. The

NDVI False Colormap 2 (NDVI-FC2) is relative NDVI where red is for min NDVI and green is for max NDVI, similar to the standard Landsat Satellite colormap.

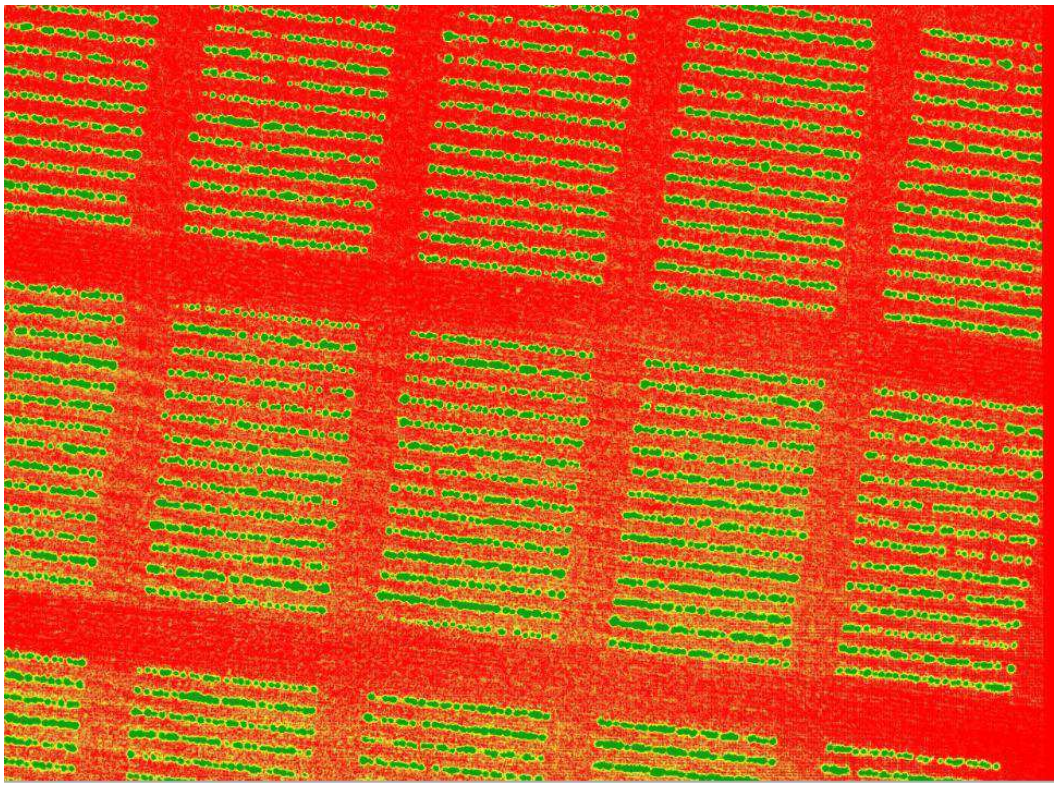


Figure 48 Example of NDVI False Colormap 2 (min NDVI Red, max NDVI Green)

9.5.NDVI-Mono

In release 2.1.2 a new NDVI colormap has been added. Run the NDVI initialization and NDVI sub-image processing exactly the same way as FC1 above, a new folder labeled (NDVI-Mono) is created for the post-processed images in the current Flight Data Folder. The NDVI False Colormap Mono (NDVI-Mono) is relative NDVI where black is minimum NDVI and white is maximum NDVI. This colormap can be beneficial to use for emergence applications when trying to determine in test plots very small plants emerging from soil.

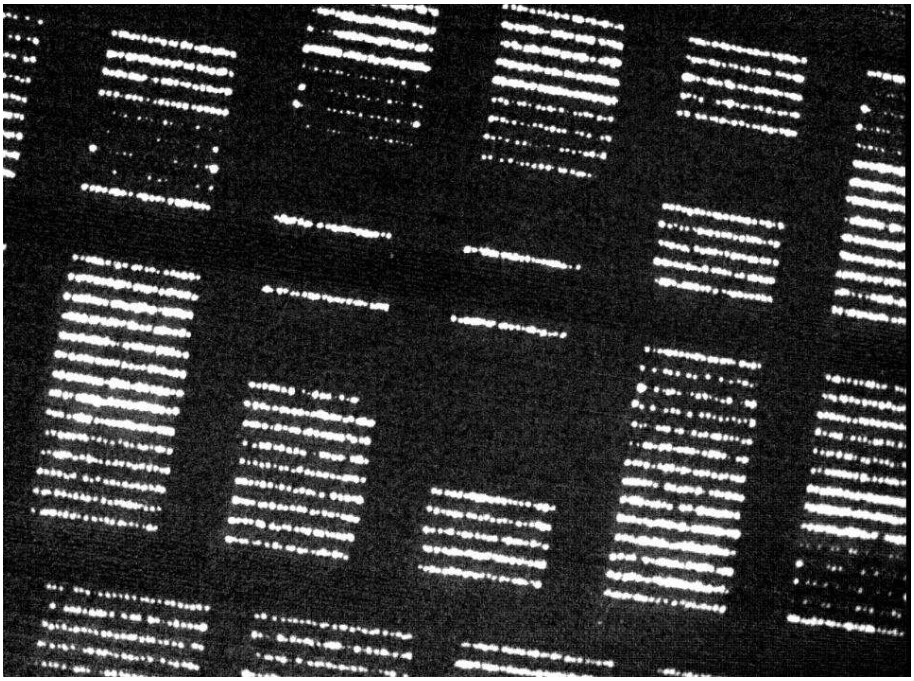


Figure 49 Example of NDVI-Mono (min NDVI black, max NDVI white)

9.6.Geo-tiff

Once the mosaics have been run in either Fast Mosaic Mode or Fine Alignment Mosaic Mode all the corresponding mosaic files are placed in the Tiles sub-folder. When generate mosaic is selected the tool probes your current hardware configuration to determine how many tiles are needed to generate the mosaics. Mosaic tiles are generated for both mosaic modes, fast or fine, and are all stored in the Tile Sub-folder in the current Flight Data folder.

The Overview Mosaics (RGB, NIR, and NDVI) for both modes are stored in this same Tiles folder for both mosaic modes. In release 2.1.2 additional Overview Mosaics are generated as .tif file format also known as a geo-tiff. These are geo-referenced mosaics for the Overviews (RGB, NIR, and NDVI) for fast and fine mosaics. This file format can easily be read into Farm Management tools like SMS, Google Earth Pro, PowerOfGround, and any other GIS tool for additional layer processing.

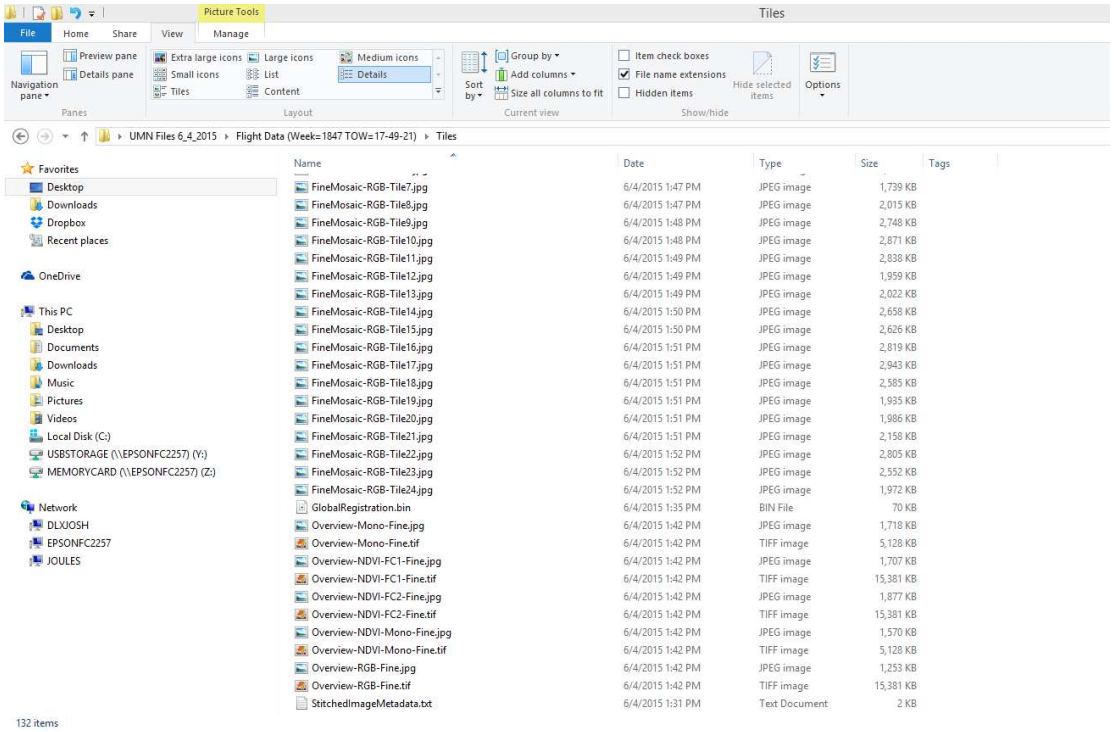

Tiles
Picture Tools
File
Home
Share
View
Manage
UMN Files 6_4_2015 ▸ Flight Data (Week=1847 TOW=17-49-21) ▸ Tiles
Favorites
Desktop
Downloads
Dropbox
Recent places
OneDrive
This PC
Desktop
Documents
Downloads
Music
Pictures
Videos
Local Disk (C:)
USBSTORAGE (\\EPSONFC2257) (Y:)
MEMORYCARD (\\EPSONFC2257) (Z:)
Network
DLXJOSH
EPSONFC2257
JOULES
Name
Date
Type
Size
Tags
FineMosaic-RGB-Tile7.jpg 6/4/2015 1:47 PM JPEG image 1,739 KB
FineMosaic-RGB-Tile8.jpg 6/4/2015 1:47 PM JPEG image 2,015 KB
FineMosaic-RGB-Tile9.jpg 6/4/2015 1:48 PM JPEG image 2,748 KB
FineMosaic-RGB-Tile10.jpg 6/4/2015 1:48 PM JPEG image 2,871 KB
FineMosaic-RGB-Tile11.jpg 6/4/2015 1:49 PM JPEG image 2,838 KB
FineMosaic-RGB-Tile12.jpg 6/4/2015 1:49 PM JPEG image 1,959 KB
FineMosaic-RGB-Tile13.jpg 6/4/2015 1:49 PM JPEG image 2,022 KB
FineMosaic-RGB-Tile14.jpg 6/4/2015 1:50 PM JPEG image 2,658 KB
FineMosaic-RGB-Tile15.jpg 6/4/2015 1:50 PM JPEG image 2,626 KB
FineMosaic-RGB-Tile16.jpg 6/4/2015 1:51 PM JPEG image 2,819 KB
FineMosaic-RGB-Tile17.jpg 6/4/2015 1:51 PM JPEG image 2,943 KB
FineMosaic-RGB-Tile18.jpg 6/4/2015 1:51 PM JPEG image 2,585 KB
FineMosaic-RGB-Tile19.jpg 6/4/2015 1:51 PM JPEG image 1,935 KB
FineMosaic-RGB-Tile20.jpg 6/4/2015 1:51 PM JPEG image 1,986 KB
FineMosaic-RGB-Tile21.jpg 6/4/2015 1:51 PM JPEG image 2,158 KB
FineMosaic-RGB-Tile22.jpg 6/4/2015 1:52 PM JPEG image 2,805 KB
FineMosaic-RGB-Tile23.jpg 6/4/2015 1:52 PM JPEG image 2,552 KB
FineMosaic-RGB-Tile24.jpg 6/4/2015 1:52 PM JPEG image 1,972 KB
GlobalRegistration.bin 6/4/2015 1:35 PM BIN File 70 KB
Overview-Mono-Fine.jpg 6/4/2015 1:42 PM JPEG image 1,718 KB
Overview-Mono-Fine.tif 6/4/2015 1:42 PM TIFF image 5,128 KB
Overview-NDVI-FC1-Fine.jpg 6/4/2015 1:42 PM JPEG image 1,707 KB
Overview-NDVI-FC1-Fine.tif 6/4/2015 1:42 PM TIFF image 15,381 KB
Overview-NDVI-FC2-Fine.jpg 6/4/2015 1:42 PM JPEG image 1,877 KB
Overview-NDVI-FC2-Fine.tif 6/4/2015 1:42 PM TIFF image 15,381 KB
Overview-NDVI-Mono-Fine.jpg 6/4/2015 1:42 PM JPEG image 1,570 KB
Overview-NDVI-Mono-Fine.tif 6/4/2015 1:42 PM TIFF image 5,128 KB
Overview-RGB-Fine.jpg 6/4/2015 1:42 PM JPEG image 1,253 KB
Overview-RGB-Fine.tif 6/4/2015 1:42 PM TIFF image 15,381 KB
StitchedImageMetadata.txt 6/4/2015 1:31 PM Text Document 2 KB
132 items

Figure 50 Example of the Windows Browser Illustrating the Geo-tiff locations in the Tiles sub-folder.

10. Hardware Requirements/Recommendations

The software can be run on any laptop/desktop computer running a windows operating system. The software utilizes both CPU and GPU processing. On the systems CPU multi-threading is enabled which automatically detects and scales according to the user's hardware available. If GPUs are available the software will utilize all processing power available. There is no limit to the scalability of the software so running the GEMS Tool on newer hardware with multi-threading and discrete GPUs will enable faster processing times for NDVI processing and mosaicing.

The recommended minimum hardware configuration is:

- 6GB RAM
- CPU should be multi-core, Ideally Intel Core i5 (4'th Gen) or better (or AMD equivalent)
- Discrete GPU is not mandatory, but is recommended.

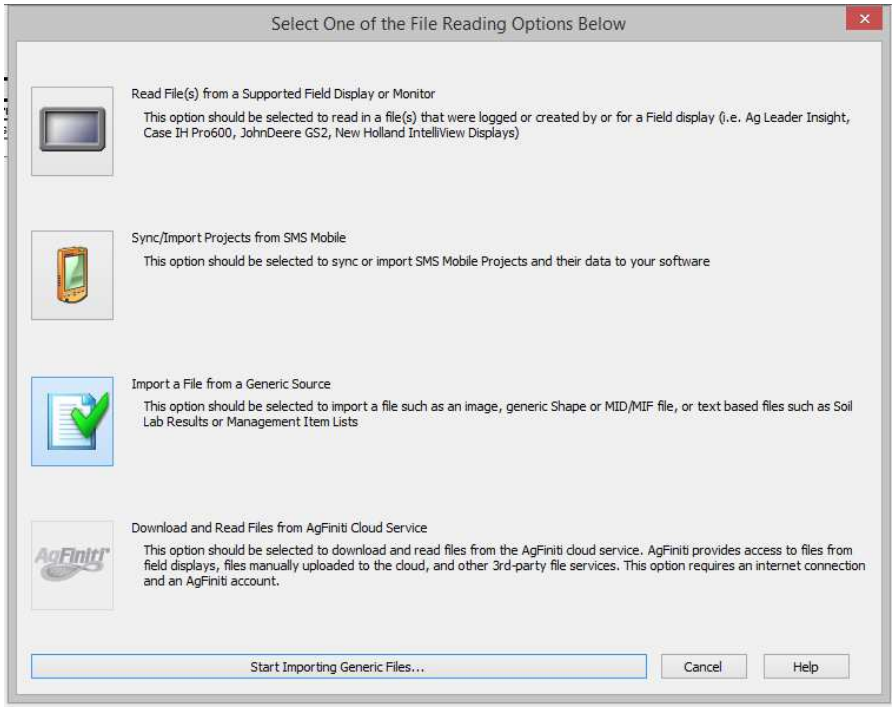
Appendix A: Abbreviations

Abbreviation	Definition
GEMS	Geo-localization Mosaicing System
GUI	Graphical User Interface
CPU	Central Processing Unit
GPU	Graphics Processing Unit

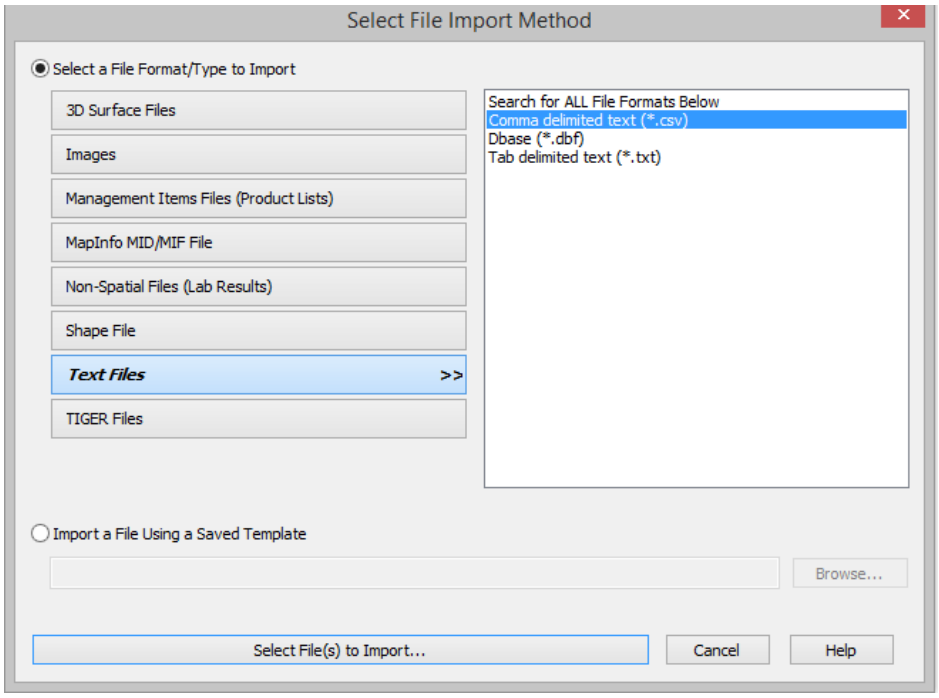
Appendix B: Using GEMS Output for SMS Farm Management Tool Prescriptions

SMS 1 Meter Resolution NDVI maps for Prescriptions:

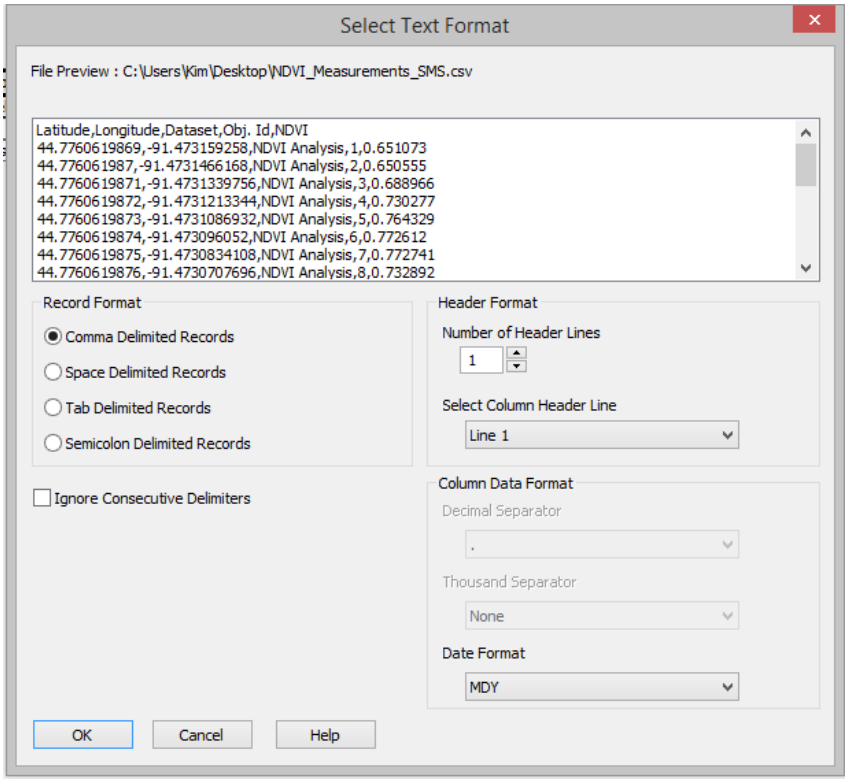
Open SMS and select Read File:


Select One of the File Reading Options Below
Read File(s) from a Supported Field Display or Monitor
This option should be selected to read in a file(s) that were logged or created by or for a Field display (i.e. Ag Leader Insight, Case IH Pro600, JohnDeere GS2, New Holland IntelliView Displays)
Sync/Import Projects from SMS Mobile
This option should be selected to sync or import SMS Mobile Projects and their data to your software
Import a File from a Generic Source
This option should be selected to import a file such as an image, generic Shape or MID/MIF file, or text based files such as Soil Lab Results or Management Item Lists
Download and Read Files from AgFiniti Cloud Service
This option should be selected to download and read files from the AgFiniti cloud service. AgFiniti provides access to files from field displays, files manually uploaded to the cloud, and other 3rd-party file services. This option requires an internet connection and an AgFiniti account.
Start Importing Generic Files...
Cancel
Help

Select Text Files CSV (comma delimeted):

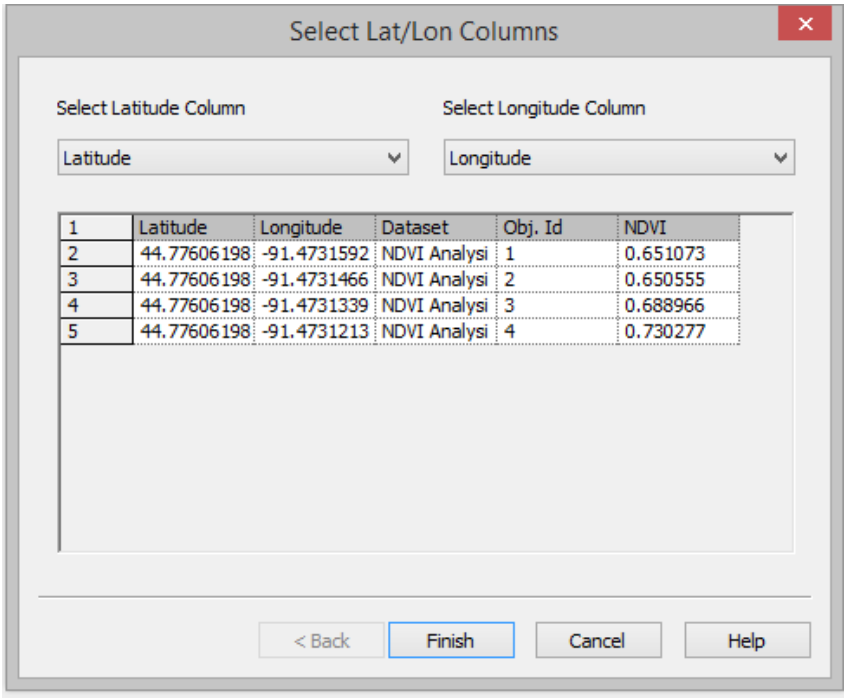


Press Select Files to Import button at the bottom of the page. Navigate to flight folder where csv export from GEMS was saved.



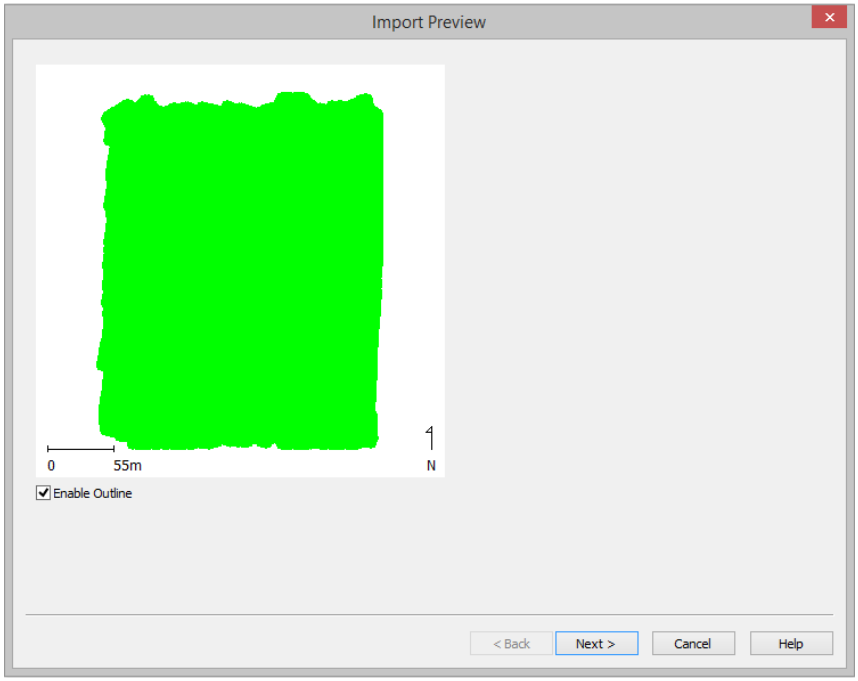
You will have to match “Select Latitude Column” with Latitude field. Additionally, match “Select Longitude Column” with Longitude field.

Select Finish.

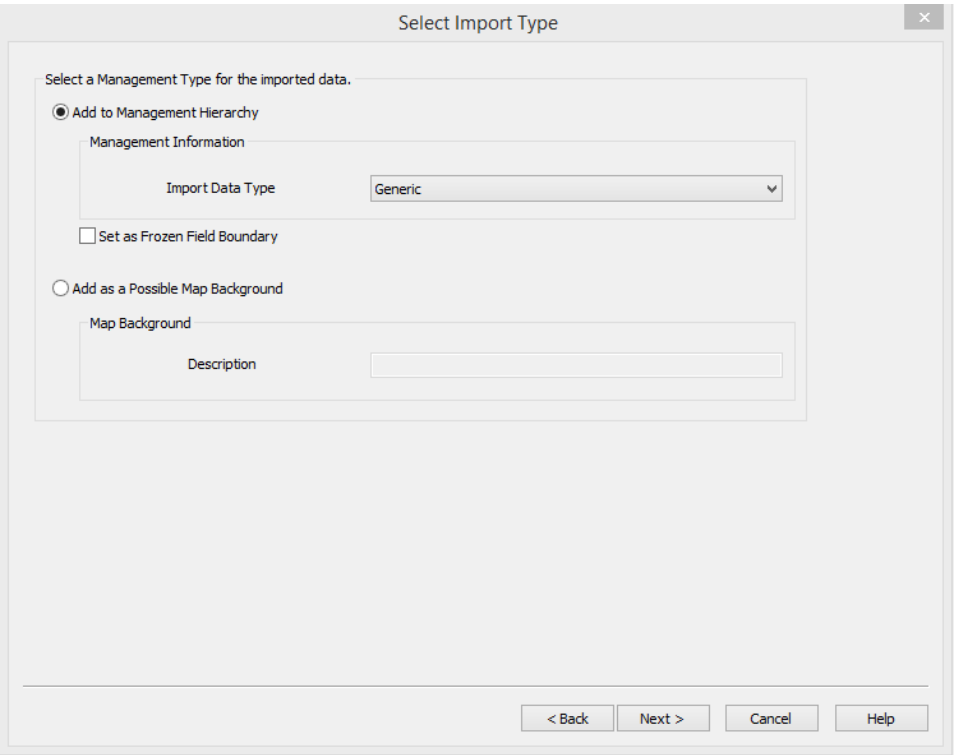


The display will be similar to the screen shot below until we adjust attributes.

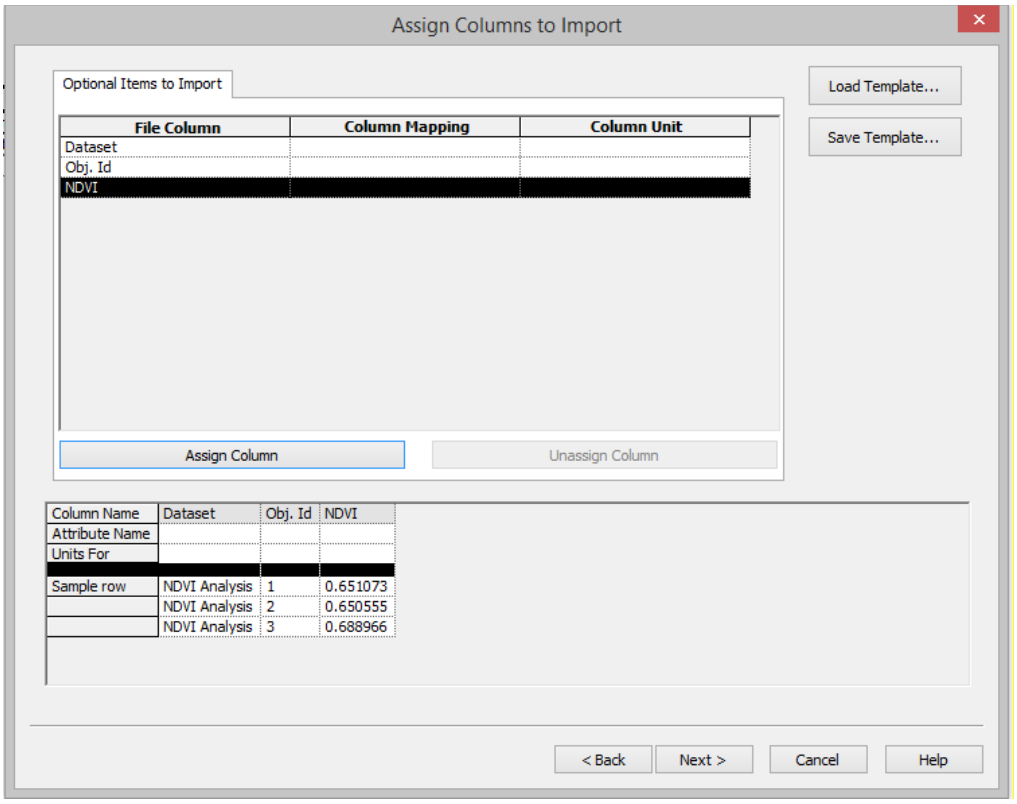
Select Next.

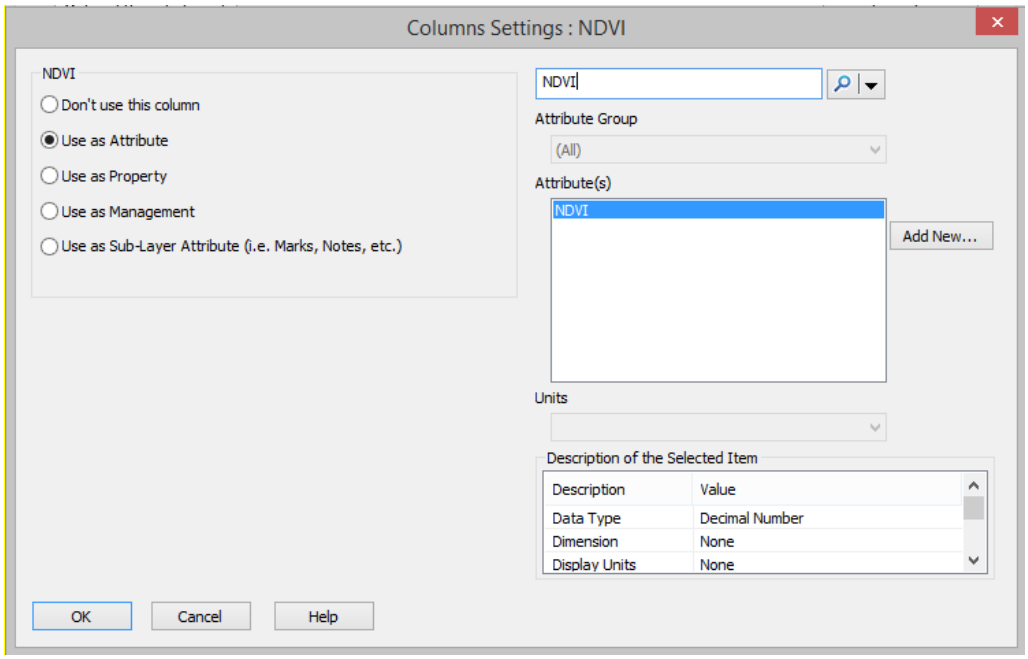


Leave default settings on this screen. Select Next.

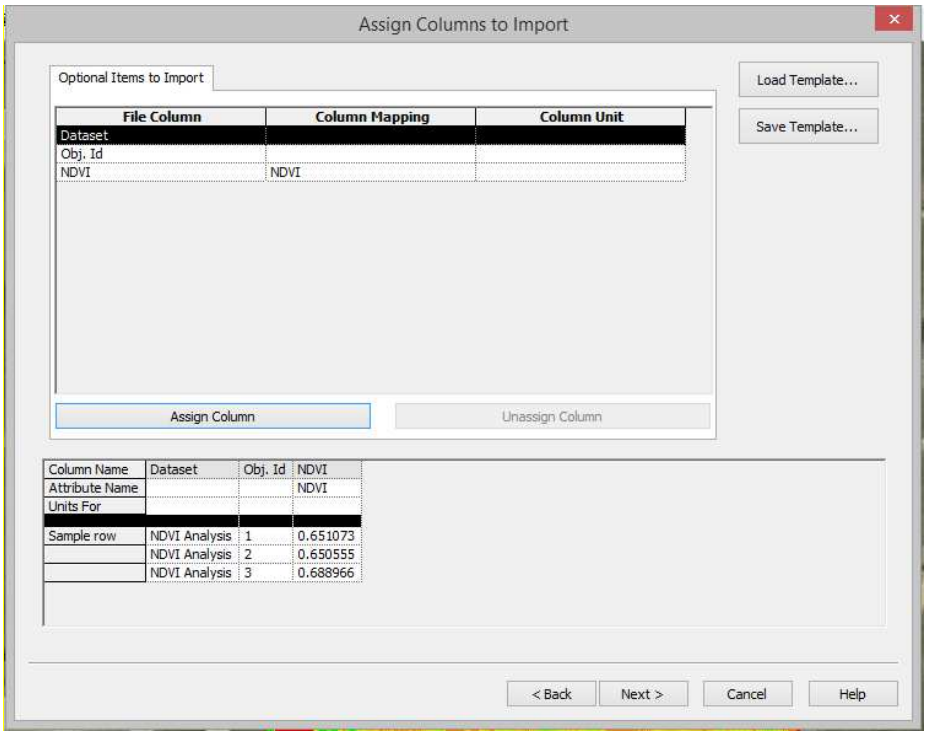


Assign columns to Import. Highlight NDVI row and hit Assign Column. Select Next.

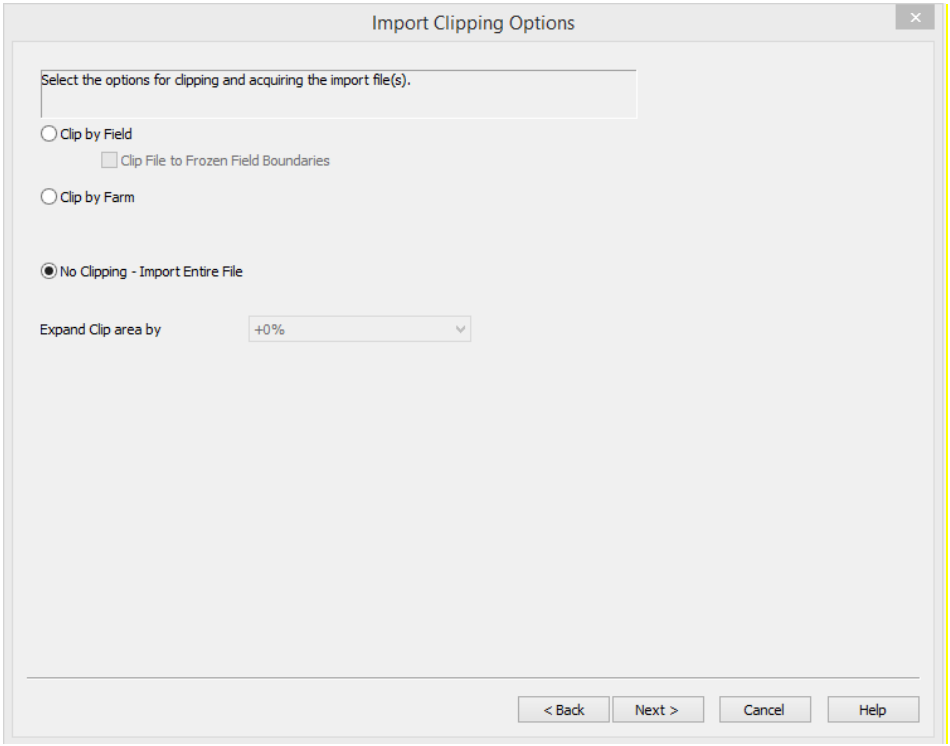

Assign Columns to Import
Optional Items to Import
Load Template...
Save Template...
File Column
Column Mapping
Column Unit
Dataset
Obj. Id
NDVI
Assign Column
Unassign Column
Column Name
Dataset
Obj. Id
NDVI
Attribute Name
Units For
Sample row
NDVI Analysis
1
0.651073
NDVI Analysis
2
0.650555
NDVI Analysis
3
0.688966
< Back
Next >
Cancel
Help


Columns Settings : NDVI
NDVI
Don't use this column
Use as Attribute
Use as Property
Use as Management
Use as Sub-Layer Attribute (i.e. Marks, Notes, etc.)
NDVI
Attribute Group
(All)
Attribute(s)
NDVI
Add New...
Units
Description of the Selected Item
Description
Value
Data Type
Decimal Number
Dimension
None
Display Units
None
OK
Cancel
Help

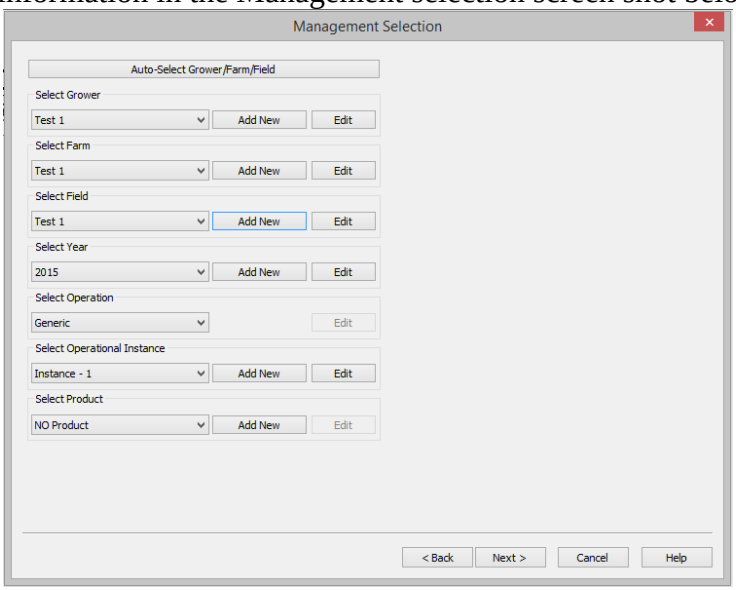
The Assign Columns screen should now look like the screen shot below with NDVI populated in Column Mapping. Select Next.



Clipping is not needed. This is dependent on Farmer/ consultants preference.

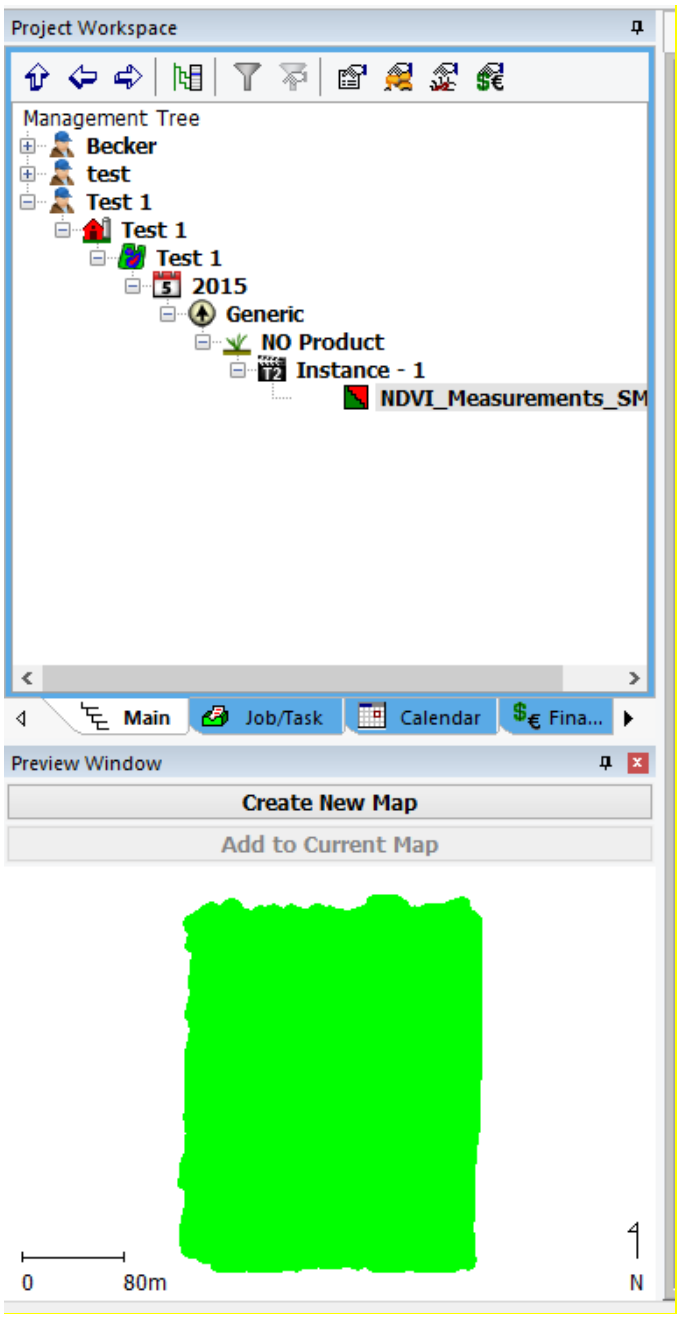


Fill in farm/grower information in the Management selection screen shot below.

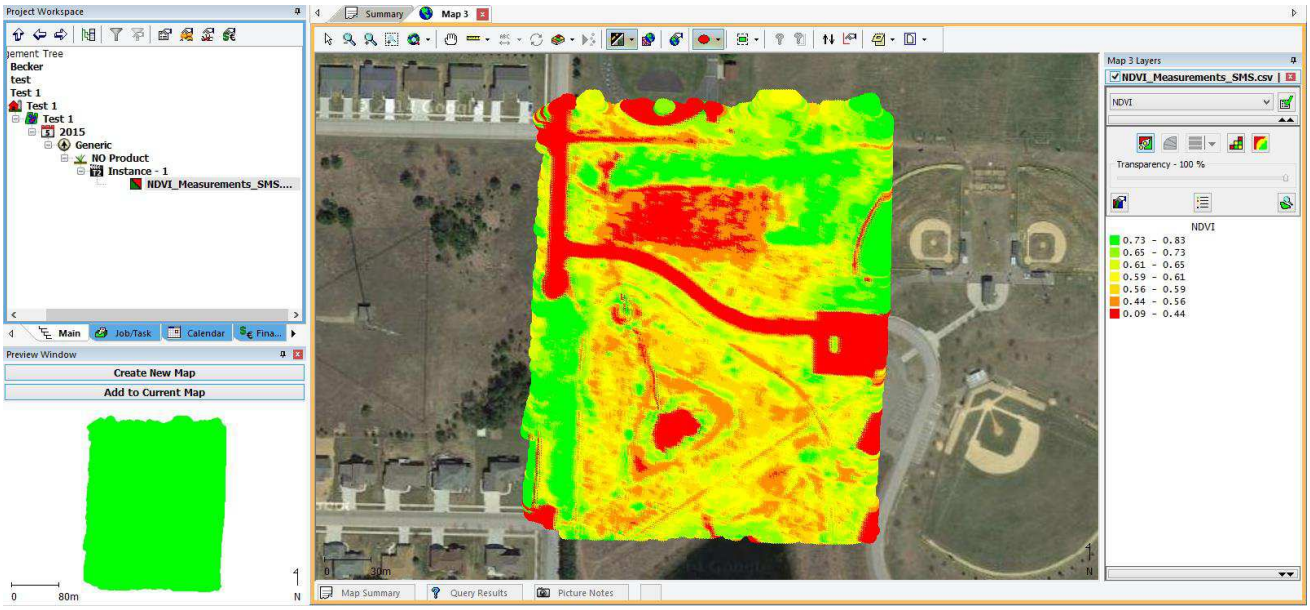


Select finish.

In Project Workspace open the Grower that was assigned above and select the imported NDVI map. Select Create New Map.

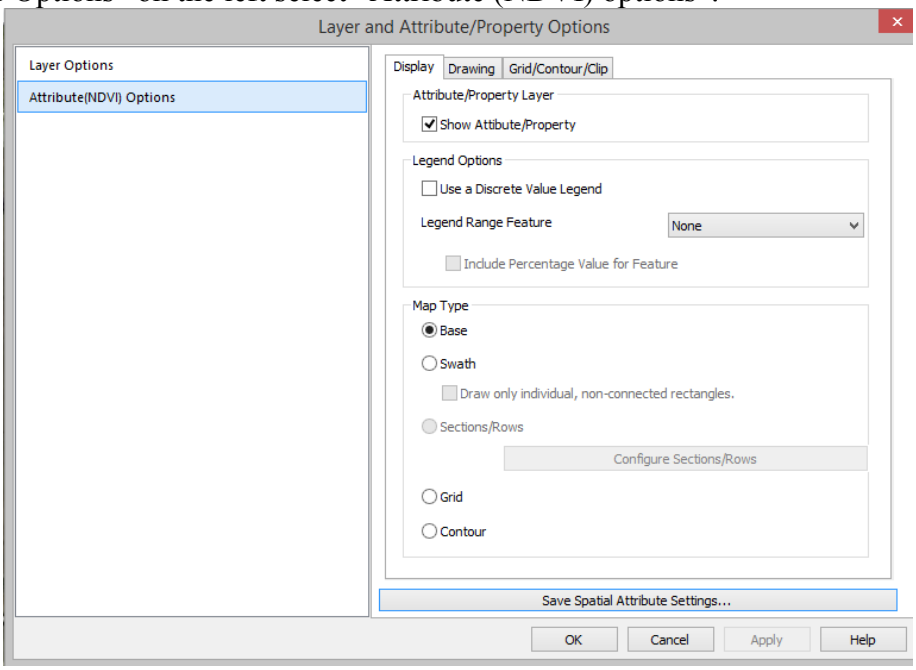

Project Workspace
Management Tree
Becker
test
Test 1
Test 1
Test 1
2015
Generic
NO Product
Instance - 1
NDVI_Measurements_SM
Main
Job/Task
Calendar
Fina...
Preview Window
Create New Map
Add to Current Map
0
80m
N

On the upper right side in the Map Layers make sure the attribute selected is NDVI.

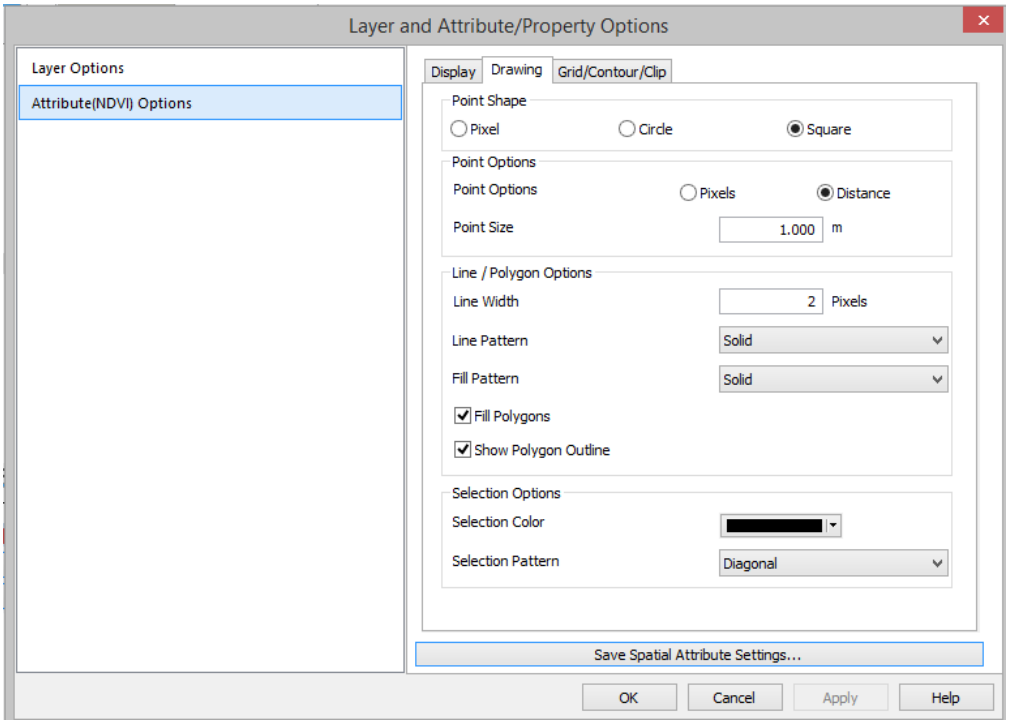


To make the layer look more appealing the user can change style preferences. In the right hand side menu labeled layers Select the layer and attribute options button .

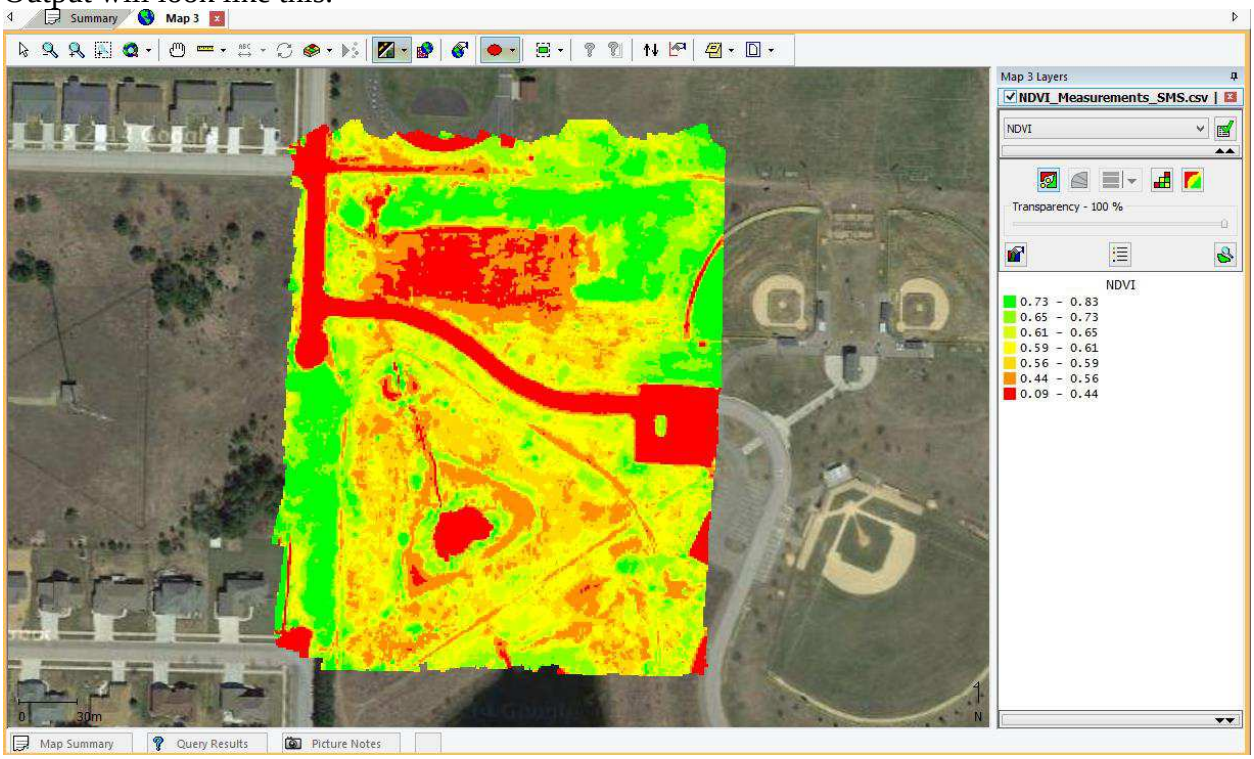
In the "Layer Options" on the left select "Attribute (NDVI) options":



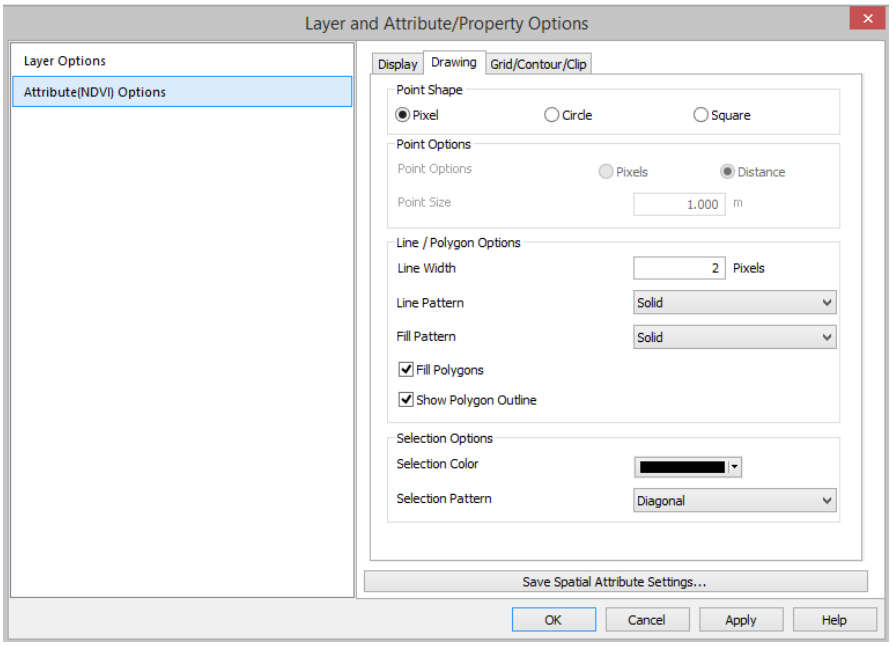
Open the Drawing Tab. Select "Point Shape" as a Square and enter in "Point Options" the "Point Size" to be 1 meter.



Output will look like this:



If you select "Pixel" as the "point shape":



Output will look like this: